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ABSTRACT

This course is intended to be a common core of instruction for both electrical meter workers and station wirer apprentices and, in some cases, power station operators, in their first two years of training. It is designed to be used either in formal classroom work or for home study on a correspondence basis. Introductory materials include a list of references and information on apprenticeship. The eight units consist of one to four lessons each. Unit topics include introduction to electricity, direct current circuits, alternating current, meters and instruments, power sources, electric motors, and electrical drawings and diagrams. At the beginning of each unit a list of the lesson goals, directions, and self-help questions are provided. Each lesson cites the required reference or references, provides any additional information needed, and presents check-up questions. The answers provided in the appended Answer Book follow the same order as the course book, and supply both questions and answers. (YLB)

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This project was developed under a subcontract from the Oregon Department of Education by Apprenticeship program at Lane Community College, Eugene, Oregon.

STATEMENT OF ASSURANCE

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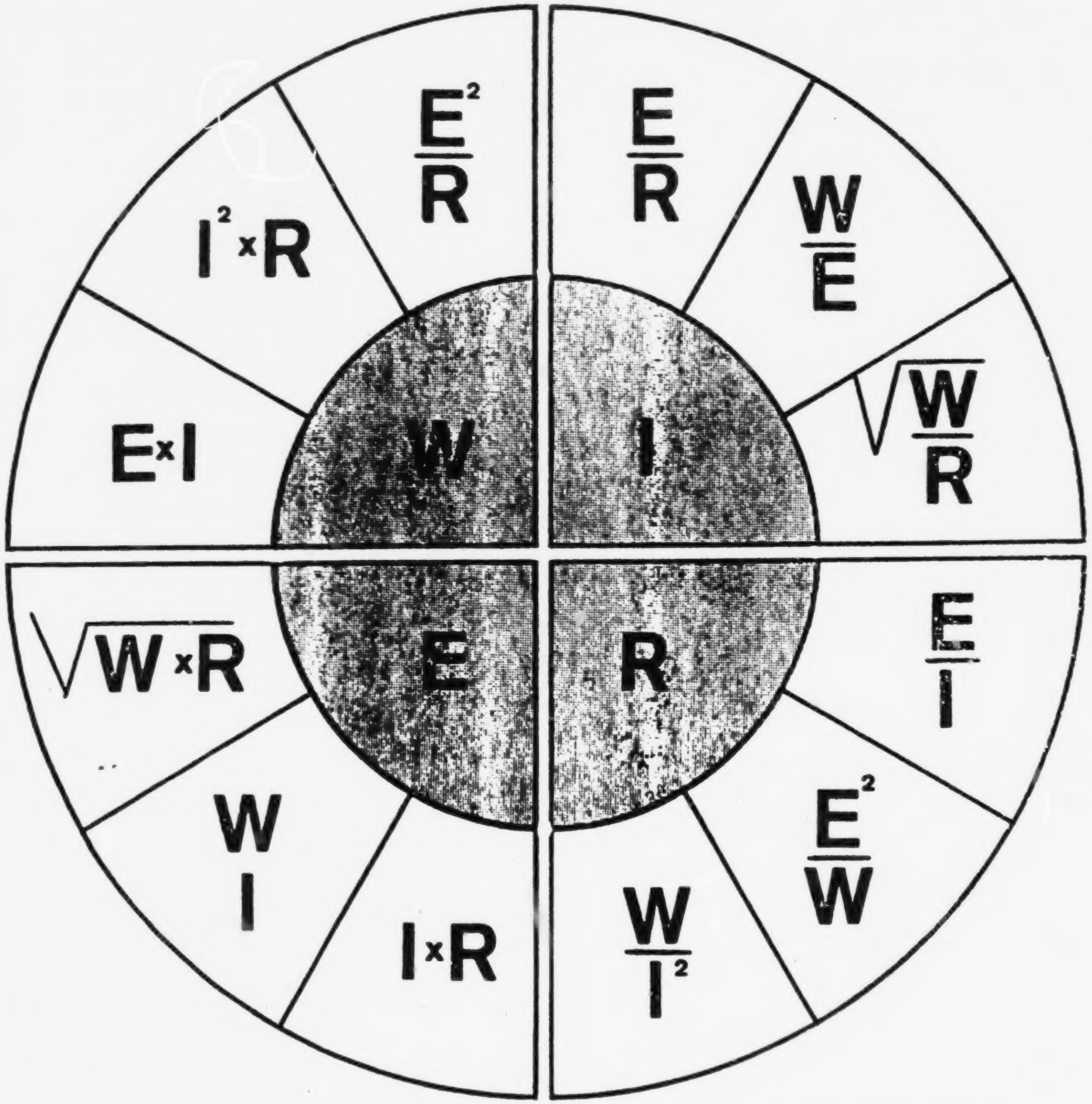
ELECTRICAL FORMULAS


W
I
E
R
$\frac{E^2}{R}$
$I^2 \times R$
$E \times I$
$\frac{E}{R}$
$\frac{W}{E}$
$\sqrt{\frac{W}{R}}$
$\sqrt{W \times R}$
$\frac{W}{I}$
$I \times R$
$\frac{E}{I}$
$\frac{E^2}{W}$
$\frac{W}{I^2}$

EXAMPLE: If you want to find the amperes and you have the voltage and wattage, you look in the square under the I (ampere) and find the formula W/E or W - E and solve.

If the circuit takes 50 watts at 100 volts, using the above formula, divide 50 by 100 and you get 0.5 I (amps).

REFERENCES

REQUIRED REFERENCES

Mileaf, Harry, Electricity One-Seven, Volumes 1-7, Hayden Book Company, Inc., New York.

Carr, Clifford C., American Electricians' Handbook, (For wireman apprentices), Ninth Edition. McGraw-Hill Book Company, Inc., New York.

Recommended Reference for a review of mathematics: Singer, B. B., and Forster, Harry, Basic Mathematics for Electricity and Electronics, Fifth Edition.

HOW TO USE YOUR COURSE OF TECHNICAL INFORMATION

In order to use your course effectively you must have:

1. Your own copy of each of the required references.

2. A large three-ring binder, 8 1/2 x 11", in which to keep your completed lessons.

3. Any additional references your instructor may require.

This course was developed and designed to be used either in formal classroom work or for home study on a correspondence basis if the wide-spread location of apprentices makes class work impractical.

The course is intended to be a common course of instruction for both electrical meterman and station wireman apprentices in their first two years of training. The third year study is specialized. Metermen will study material that is related to their speciality and wiremen will study from material related to electrical construction and maintenance of power stations.

Power station operator trainees will also find that this basic course provides a good technical background as well as the general knowledge so essential to understand the work performed on the job.

We feel that no electrical worker can become highly skilled or proficient in the handling of electrical apparatus unless that individual is well informed on the elementary theory and the basic rules governing electricity and magnetism. Most of the basic ideas of electric phenomena are based upon mathematical reasoning and stated in mathematical terms. The many problems found in this course are intended to lay a foundation that will help you learn the more technical and complicated engineering principles that you must understand to become a qualified and skilled journeyman and to move into more advanced and technical positions later on.

During your apprenticeship period people are especially willing to help you, so take advantage of your opportunities. What you do not learn as an apprentice you will have to learn as a journeyman on your own.

What is Apprenticeship?

Apprenticeship, as a form of education, has been in existence in one form or another for 4,000 years; yet a great many people today are not aware of the role it plays in maintaining our supply of skilled craftsmen for industry.

Webster defines an apprentice as "One who is bound to a master to learn an art or trade." A more literal and current definition is, "a person who contracts with an employer to learn a skilled occupation under a specific training plan." This plan provides for the apprentice to do productive work in exchange for less than journeyman wage rate, and to receive instruction and continuous supervision from a competent journeyman.

As a practical point, apprenticeship training, by its very nature, is applicable only to the learning of skilled occupations. It has the advantage of being productive and earning an income while learning, practicing, and developing the skills required. It requires supplemental schooling called "related training" to provide the theoretical knowledge of the trade while the on-the-job part develops the practical skill applications. Occupations of clerical or professional nature are more appropriately learned by academic process; hence, the limitation of apprenticeship training to the skilled occupations.

The training plans, known as "apprenticeship standards" are developed for each specific trade or craft, by persons from that particular trade or craft. These persons are formed into a committee who are experts in their field. They develop a set of "standards" which outline the work processes to be learned, the related material to study, the wage rate to be paid, and other working conditions which will insure the complete training necessary to produce a truly skilled craftsman, worthy of the title "JOURNEYMAN."

A WORD TO THE INSTRUCTOR

The material presented in this course of study is intended to serve as a guide for those who are studying to become qualified electrical power station workers. It is not possible to cover all the aspects in great depth, however, we have attempted to organize the instructional material in a logical sequence covering those principles which are essential in electrical technology. The instructor can be a big factor in generating student interest by presenting job-related experiences and emphasizing the practical application where a particular theory is utilized. The greater the learners interest, the easier the task of teaching.

This author feels that if an electrical lab is available for classroom work, the instructor can perform many experiments that will allow the students to see and prove to themselves that the theories presented in the textbook really work. Electricity is something the students cannot see, but if they see the effects of electricity can be measured along with things like ohms, amps, volts, watts, sinwaves, phase angles and phasers, to mention a few, they will begin to believe in tangeable, measureable quantities. Let the students participate in experiments and discussion. They may learn more from a discussion in which they participate than they do from a lecture.

As stated before, this is intended to be a common course of study for the first two years of training for both wiremen and metermen and, in some cases, power station operators. It should be recognized that all the assignments are not of equal importance to all students. Students' needs will differ and you may find it desirable to devote more attention to one portion of the course than another.

The section on subject of "Print Reading" should be introduced to the students as soon as they are familiar with some of the most basic electrical concepts. By the time they have covered series and parallel circuits, they will comprehend what a complete circuit consists of. It is best that no particular period of this course be devoted exclusively to Print Reading, but Print Reading exercises and lessons be interspersed throughout the entire course in a manner that will enable the individual student to gain the most benefit.

ELECTRICAL THEORY

UNIT 1

INTRODUCTION TO ELECTRICITY

This unit contains the following lessons:

BASIC PRINCIPLES OF ELECTRICITY

Lesson 1-1-1: The Electron Theory Simplified
Lesson 1-1-2: How Electricity is Produced
Lesson 1-1-3: Mathematics Review

ELECTRICAL CURRENT

Lesson 1-1-4: Current Flow - What It Is
Lesson 1-1-5: Mathematics Review

MAGNETISM

Lesson 1-1-6: Magnetic Fields

VOLTAGE AND RESISTANCE

Lesson 1-1-7: What Causes Current Flow?
Lesson 1-1-8: Resistance
Lesson 1-1-9: Algebra Reveiw
Lesson 1-1-10: Equations
Lesson 1-1-11: Problems Involving Resistance and Wire Size
Lesson 1-1-12: Resistance and Temperature

BASIC PRINCIPLES OF ELECTRICITY

Careful study of the lessons which follow will help you to acquire:

1. An understanding of the fundamental and simplified version of the electron theory and its relationship to electrical principles and physical laws.

2. A knowledge of the various methods which can be used to produce electricity, with emphasis placed on the two common methods used as a source of electric power.

3. An appreciation of the place occupied by the electron theory and its application in future problems that you will encounter in the electrical field.

4. The ability to use standard terminology when reading, studying, writing, or otherwise expressing ideas in your trade.

Directions:

1. Think about and attempt to answer the study-help questions before starting the lessons. Keep them in mind as you study.

2. Study the references thoroughly and make certain that you understand each theory and principle before advancing to the next topic. Familiarize yourself with all new words, terms, and definitions.

3. Make a list of new terms and definitions in your notebook.

4. Write out and hand in the answers to all the check-up questions after carefully considering the aim of the questions. When words alone fail to convey your meanings, make sketches, drawings, or diagrams.

Study-help questions:

1. Because no person has ever seen an electron, how can we assume there is such a thing?

2. The entire study of electricity is based on what theory?

3. What is the relationship between a molecule and an atom?

4. What are the six basic sources of energy that can be used to produce electricity? Which two methods are the most important for commercial application?

5. Based on the electron theory, why is copper a better conductor than glass?

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6. Why are there no perfect conductors or perfect insulators?

7. How do you intend to fix electrical terms and their meanings in your mind?

8. Compare a planetary electron with a free electron.

Lesson 1-1-1
THE ELECTRON THEORY SIMPLIFIED

Required reference:

Electricity One-Seven,

Check-up: (1-1-1)

1. What is an electron? Proton? Neutron? Nucleus? Atom? Molecule?
2. How do "bound" electrons differ from "free" electrons?
3. Why is the electron theory important to you with regard to your future work in the electrical field?
4. Basically, all matter is what, according to the electron theory?
5. Scientific fact proved beyond doubt is known as a "law." Is the electron theory a law?
6. According to the electron theory, what is an electric current?
7. In what way does a carbon atom differ from a hydrogen atom?
8. Approximately how many different kinds of atoms exist?
9. What is a compound?
10. In an atom, what relationship exists between positive charges, which are called "protons," and negative charges, which are called "electrons?"

Lesson 1-1-2

HOW ELECTRICITY IS PRODUCED

Required reference:

Electricity One-Seven,

Additional information:

You have learned from study of the electron theory that electricity is the effect of electrons moving from one point to another. Some form of energy must be present to bring this condition about. There are six basic sources of energy which can be used. They are: FRICTION, PRESSURE, HEAT, LIGHT, MAGNETISM, and CHEMICAL ACTION. Of these six sources, you will usually use only magnetism and chemical action. Electric charges obtained by the other methods are only used in special applications and are never used as a source of electrical power. A study of the six basic sources will give you a better picture of how electricity is produced.

How Chemical Action Produces Electricity. Electricity from chemical action is very important. You will have occasion to use dry cells, storage batteries, and standard cells in your work as a meterman or wireman. You will use dry cells in flashlights, ohmmeters, and resistance bridges. Dry cells are also used for testing the accuracy of millivoltmeters and milli-ammeters in the laboratory. Storage cells are used for a current supply in testing direct current watt-hours meters, for control and operating bus in stations, and in the laboratory for a current supply when checking the accuracy of ammeters and wattmeters. The standard cell is used in the laboratory as a voltage supply in connection with what we call a potentiometer used for checking the accuracy of various kinds of instruments. Therefore, it will pay anyone who aspires to being a meterman or wireman to learn at least a little about cells and batteries.

The open-circuit voltage of a dry cell is 1.5 volts. A lead-acid cell has an open-circuit voltage of 2.4 volts when fully charged, which settles back to 2 volts when discharged. The electrolyte of a lead-acid storage cell is dilute sulphuric acid and we tell the condition of the cell--that is, how much it is charged--by testing the specific gravity of the solution with a hydrometer. When the cell is fully charged, the electrolyte has a specific gravity of 1.280; when discharged the specific gravity is 1.120.

How Magnetism Produces Electricity. Magnetic materials differ greatly in the amount of magnetism that they can retain. If a piece of soft iron or soft steel is magnetized, it makes a stronger magnet while the magnetizing force is applied than does a hard piece of steel. However, the instant the magnetizing force is removed, the soft steel or soft iron loses practically all of its magenetism while a relatively large amount remains in the piece of hard steel. Therefore, soft steel cannot be used to make permanent magnets. The ability of a material to retain magnetism is called RETENTIVITY.

When a magnetizing force is applied to a piece of magnetic material, all of the tiny magnets are forced into a position so that all of their like poles are pointing in the same direction. It seems reasonable to assume that the harder the steel the more difficult it is to force the tiny magnets to line up; but once they are lined up, they do not readily return to their original positions. For this reason, permanent magnets which are to be used in electric watt-hour meters are made of the best grades of highly-tempered steel. For a watt-hour meter to maintain its accuracy over a long period of time, it is absolutely necessary that its permanent magnet retain a constant amount of magnetism for an indefinite period of time.

Watt-hour meters and, for that matter, every electrical measuring instrument having a permanent magnet must be handled carefully. A jar or a blow may cause some loss in the magnetism, thereby causing inaccuracies in the measurements. For the same reason, an electric current should never be passed through a permanent magnet.

A piece of steel placed across the poles of a magnet to clean it may appreciably change the field of the magnetic flux and cause inaccuracy in the watt-hour meter. Hence, a magnet cleaner is made of bronze or some other nonmagnetic material when it is to be used for cleaning the permanent magnets of watt-hour meters.

A steel screwdriver should not be placed in close proximity to the poles of the permanent magnets of watt-hour meters for exactly the same reason.

We might say something about the movements of a wire past a magnet or the movement of a magnet past a wire, which is discussed in the beginning part of Electricity One-Seven. It has been found that if a conductor cuts 100,000,000 lines of force per second, a pressure of 1 volt is produced between the ends of the wire. This number 100,000,000 is usually written 10^8 and is read "ten-to-the-eighth." Therefore, the formula for the voltage, or emf, produced is:

$$E = \frac{0 \times N}{\times 10^8}$$

Where: E = Voltage
0 = Total number of lines of force cutting one wire
N = Total number of turns of wire being cut
= Time in seconds

Thus, if we are using only one wire and we cut 10^8 lines of force per second with it, we will produce an emf of 1 volt. If two turns of wire were used under the same conditions, then we would produce 2 volts.

Check-up: (1-1-2)

1. What are some of the practical applications of the photoelectric cell?

2. Describe the basic wet cell. In what direction does the electrolyte carry the current inside the cell?

3. When two dissimilar metals are riveted or welded together for the purpose of converting heat into electricity, what is this called?

4. Give the most common use of the device in question 3.

5. When we apply pressure to a crystal of quartz we produce what is called piezoelectric electricity. What are some of the common uses for this particular type of electricity?

6. In your own words, state the law that exists with: (a) unlike charges; (b) like charges.

7. When we rub certain materials with certain materials we produce electricity. What is this electricity called?

8. Describe the three methods by which the electrical charges in question 7 may be dissipated.

9. Name one natural phenomenon which occurs due to the accumulation of static charges.

10. What is the transfer of a charge from one material to another without actual contact called?

Lesson 1-1-3
MATHEMATICS REVIEW

Recommended reference:

Basic Mathematics for Electricity and Electronics,

The student should note that a thorough understanding of mathematics is essential in numerous trades and professions and particularly so in the study of electrical and electronic subjects. Most of the electric phenomena are based upon mathematical reasoning and stated in mathematical terms. This course assumes that you have studied mathematics, but some review might be necessary because considerable time may have elapsed since you needed to do much calculation. For the student who has been away from school for sometime and feels the need to brush up to remove the "rustiness", a review of the fundamental operations-both in whole numbers and fractions-is recommended.

The electrical worker frequently meets with problems that require figuring. Most often the various calculations that may be required really depend on an understanding of mathematics. This lesson will indicate to the student just how much review is necessary. Each student must be able to judge what the individual need is.

Check-up: (1-1-3)

1. Find the sum of 131, 222, 21, and 413.

2. Find the sum of 425, 36, 9, 215, 4, and 907.

3. A pump operated 2 hours and 45 minutes to empty a tank filled with transformer oil. The meter reading showed that 4,200 gallons were removed during the first hour, 5,420 during the second hour, and 3,600 during the last 45 minutes. How many gallons of oil did the tank contain originally?

4. Four resistors, 100 ohms, 1,000 ohms, 39 ohms, and 470 ohms are connected in series. What is their total resistance?

5. Using U.S. standard, the gage and thickness for sheet steel is as follows: No. 00 - 0.2656 inches; No. 4 - 0.234375 inches; No. 7 - 0.1875 inches; No. 13 - 0.9375 inches. If one sheet of each of the gages of sheet steel were stacked together, find the approximate thickness of the stack.

6. If an electric meter registers 7,968 watt-hours at one reading, and 10,430 watt-hours at the next reading, how many watt-hours were used by the customer?

7. In the construction of one substation it was found that out of a stock of 1,037 pounds of conduit fittings there remained a quantity of 259 pounds. How many pounds were used?

8. What is the total weight of copper in 649 transformers if the amount of copper in each transformer weighs 37 pounds?

9. A tank has a capacity of 5,130 gallons. How many hours will it take to fill if oil is pumped in at the rate of 270 gallons per hour?

10. A 115 KV circuit breaker has a movable contact 7.895 inches long, but 0.725 inches of the contact has burned away. What length remains?

11. Nine equal distances of 4.75 inches are marked off on a piece of heavy copper bus. What is the total distance marked off?

12. A piece of brass tubing of 24.375 inches long is divided into equal parts measuring 1.625 inches in length. How many parts are there?

13. A technician measured seven different resistors with his ohmeter as follows: 471 ohms, 500 ohms, 490 ohms, 452 ohms, 460 ohms, 420 ohms, and 485 ohms. What was the average value of the seven resistors?

14. A steel I-beam expands 0.01 percent of its length when exposed to the sun. Find the increase in the length of an I-beam 25 feet, 8 inches long.

15. Gage sheet copper (#25) is 0.179 inch thick and weighs 0.811 pound per square foot. Find the thickness of a pile of 48 such sheets.

16. From problem 15, find the weight of this number of sheets if each sheet has 6.25 square feet.

17. A brass rod was cut into 5 pieces of lengths: 4 1/5, 3 5/8, 6 1/2, 7 9/16, and 2 3/4 inches, respectively. How long was the rod if 1 1/16 inches was wasted?

18. Find the difference between a pipe nipple 3 1/8 inches long, and one 2 3/4 inches long.

19. What is the product when you multiply 2/3 by 5/7?

20. In the blueprint of a substation control house, 1/4 inch in the print represents 1 foot in the actual house. Find the dimensions of the battery room that measures 2 1/2 by 4 1/8 inches.

Lesson 1-1-4
CURRENT FLOW--WHAT IS IT?

Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Check-up: (1-1-4)

1. What is current flow?

2. What makes an atom release its "free" electrons?

3. According to the electron theory, in which direction does the current move: (a) external to a battery, or (b) internally?

4. Describe the action of "free" electrons in a wire when current starts to flow.

5. Are any of the "free" electrons lost as a result of current flow?

6. What is the instrument used to measure current flow called?

7. If we are passing a current at the rate of 1 coulomb per second: (a) What practical unit is used to measure the current that is flowing? (b) What does an instrument used to measure current actually measure according to the electron theory?

8. How many amperes (a) in 1 milliampere; (b) in 1 microampere; (c) in 50 microamperes; and (d) in 40 milliamperes?

9. Describe what is meant by "potential difference," "voltage," and "emf."

10. What is the practical unit of electric potential? How many in 1 KV?

Lesson 1-1-5

USING FORMULAS FOR PROBLEM SOLVING

Recommended reference:

Basic Mathematics for Electricity and Electronics,

This lesson continues the review of mathematics and deals with the solution of practical problems by applying the correct formula. You may remember that a rule stated in letters and signs is called a formula. It is a shorthand way of stating a rule. Also, the practical person comes in contact with weights and measures so often that it is absolutely necessary that the systems of measurement be understood. The metric system was invented for simplicity. The terms "kilowatts," "kilohertz," "milliamperes," and others used commonly in electrical work, are akin to the metric system. We often find it convenient, if not necessary, to be able to change measurements in the common system to an equivalent in the metric system, or vice versa.

Measures of Length

12 inches = 1 foot
3 feet = 1 yard
1,760 yards = 1 mile
5,280 feet = 1 mile

Square Measure

144 square inches = 1 square foot
9 square feet = 1 square yard
4,840 square yards = 1 acre
640 acres = 1 square mile

Measures of Volume

1,728 cubic inches = 1 cubic ft.
27 cubic feet = 1 cubic yd.

Liquid Measure

231 cubic in. = 1 U.S. gal.
0.1337 cubic ft. = 1 U.S. gal.
7.48 U.S. gal. = 1 cubic ft.

Metric and English Conversion Table

1 centimeter = 0.3937 inch
1 millimeter = 0.03937 inch
1 meter = 39.37 inches
= 3.2080 feet
= 1.0936 yard
1 kilometer = 0.6214 mile

1 inch = 2.54 centimeters
1 inch = 25.4 millimeters
1 foot = 304.8 millimeters
1 foot = 0.3048 meter
1 yard = 0.9144 meter
1 mile = 1.609 kilometer

Check-up: (1-1-5)

1. A tool box measure 2-feet 3-inches long, 18-inches wide, and is 1-foot deep. What is the volume?

2. What is the volume of a cylindrical oil tank 3-feet in diameter and 6-feet, 6-inches high?

3. If 1 gallon equals 231 cubic inches, what is the capacity of the above tank in gallons?

4. How many cubic feet of cement are required for a retaining wall that is 20 feet long, 8 feet high, and 2 feet thick?

5. A forged steel shaft for a generator is 18 inches in diameter and 10 feet long. If forged steel weighs 0.283 pounds per cubic inch, what is the weight of the shaft?

6. What is the distance across the corners of a square nut that is 2 3/8 inches on a side?

7. An 8-foot high chain-link fence is to be installed around the perimeter of a distribution substation. The area to be enclosed measures 180 feet by 125 feet. How many square feet of fencing will be required?

8. A man's height is 174 centimeters. What is his height in feet and inches?

9. What is the diameter in inches of the bore of a 75 millimeter gun?

10. A pipe used as a conduit for electric wires has an inside measurement of 2.17 inches and an outside measurement of 2.39 inches. How thick is the pipe?

11. A flat copper bar to be used behind a switchboard is required to be exactly .500 inch wide. When measured by micrometer caliper the width is found to be .499 inch. How much too small is it?

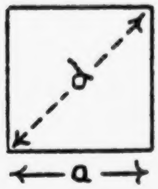
12. In an induction motor the rotating part, which is called the rotor, is surrounded by a stationary part called the stator. In order that the rotor may revolve freely, the hole in the stator must be somewhat larger than the rotor. This leaves what is known as an air-gap between the rotor and stator. If the hole in the stator is 24.375 inches in diameter and the diameter of the rotor is 24 inches, what is the width of the air gap?

13. A microwave antenna tower is held in position by three guy wires that reach the ground 49 feet from the foot of the tower. Find the length of the guy wires if they are fastened to the tower 70 feet from the ground.

14. A circuit breaker that is equipped with a pneumatic operator, air-compressor and control system has a normal operating pressure of 225 p.s.i. For closing the breaker, air is admitted to the mechanism cyclinder by an electrically operated control valve. If the closing piston had a 3-inch diameter, what force would be exerted to close the circuit breaker?

USING FORMULA

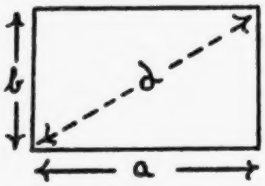
where: a, b, c, d, s denotes length & width
A, denotes area & V, denotes volume



SQUARE

$A = a^2$

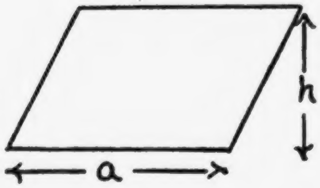
$d = a\sqrt{2}$



RECTANGLE

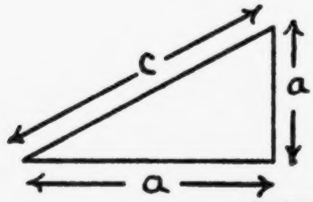
$A = a\,b$

$d = \sqrt{a^2 + b^2}$



PARALLELOGRAM

$A = a\,h$

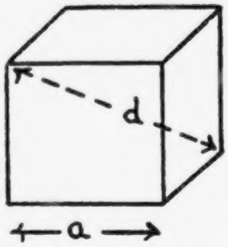


RIGHT TRIANGLE

$A = \frac{1}{2}\,a\,b$

$c = \sqrt{a^2 + b^2}$

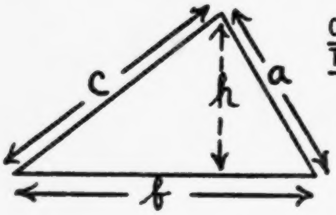
$a = \sqrt{c^2 - b^2}$



CUBE

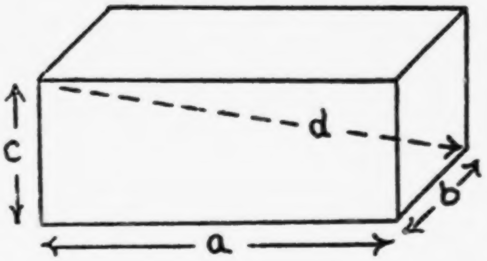
$V = a^3$

$d = a\sqrt{3}$



OBLIQUE TRIANGLE

$A = \frac{1}{2}\,b\,h$



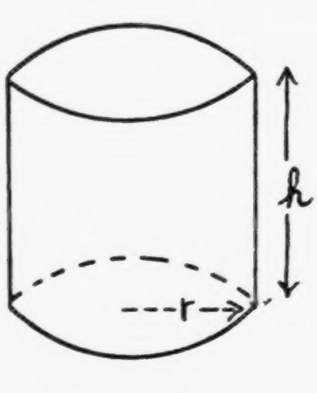
RECTANGULAR CONTAINER

$V = a\,b\,c$

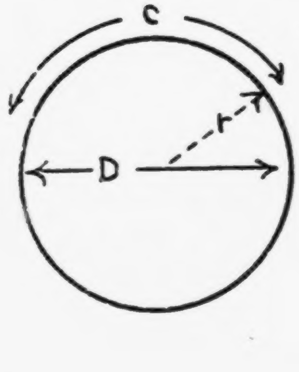
$d = \sqrt{a^2 + b^2 + c^2}$

CYLINDER

$V = (\pi r^2)\,h$



CIRCLE



$C =$ circumference

$D =$ diameter

$r =$ radius

$\pi =$ 3.14

$$C = 2\pi r = \frac{1}{4}\pi D^2$$
$$A = \pi r^2 = \frac{1}{2}\,r\,C$$

MAGNETISM

You are to acquire from your study of the following lessons:

1. An understanding of the relationship between the direction of current flow and the direction of the magnetic field around a current-carrying wire and a current-carrying loop or coil.

2. An ability to apply the rules for finding the direction of the magnetic field around a current-carrying conductor and determining the magnetic polarity in a loop or coil.

3. A knowledge of how the magnetic field strength can be increased in a current-carrying coil.

4. An understanding of the principles and operation of basic meter movements.

Directions:

1. Keeping the study-help questions in mind, carefully study the required reference and any additional references assigned by your instructor.

2. Familiarize yourself with all new words, terms, and definitions. Add them to the list in your notebook.

3. Sketch in your notebook the magnetic fields of conductors and coils, and the basic ammeter movement.

Study-help questions:

1. How do you apply the left-hand rule for a conductor carrying current?

2. How do your apply the left-hand rule for current-carrying coils?

3. What is the principle of the electromagnet? What are some of the industrial applications of the electromagnet?

4. How is it possible to increase flux density in the magnetic field of a coil?

5. What are the two common methods of increasing field strength in a current-carrying coil?

6. What is a horseshoe type magnet? How is it used in electric meters?

7. What is a ferromagnetic material?

8. What is meant by "reluctance of a material?

9. Name the parts of a current-measuring meter.

Lesson 1-1-6
MAGNETIC FIELDS

Required reference:

Electricity One-Seven,

Check-up: (1-1-6)

1. Remembering that the left-hand rule is based on the electron theory that current flow is from the negative to the positive terminals, state the left-hand rule for:

   a. a conductor carrying current
   b. a coil of wire carrying current

2. If you suspend a coil of wire by a thread so that it can move freely, what happens when you pass a current through it? What does this prove?

3. In what two ways can you increase the strength of magnetism in a coil carrying current?

4. In what way can you further increase the flux density and, therefore, increase the magnetism of the coil? Why is this so?

5. What do you use to determine the direction of a magnetic field around a current-carrying conductor and how can you verify the results?

6. How can you show the pattern of the lines of force around a permanent magnet or around a coil of wire carrying current?

7. How can you verify the assumption that the magnetic lines of force travel from a north pole to a south pole?

8. What sort of a pattern of magnetic field exists around a straight conductor carrying current?

9. A horseshoe magnet consists of a horseshoe-shaped piece of iron with a coil of wire wound around each end. The coils are wound in the same direction. What will happen if the direction of one of these coils is reversed and current is passed through the coils?

10. Do lines of force ever cross or unite with each other?

11. Where is the magnetism of a magnet concentrated?

12. Why is it important to handle watt-hour meters carefully?

13. State the law that applies to like and unlike poles of a magnet?

14. Why do lines of force travel easier through iron than through air?

15. How do we shield an instrument from the flux lines of a magnetic field?

16. What polarity does a piece of iron assume when placed in a magnetic field?

17. When a piece of magnetic material has all of the lines of force that it will hold, what do we say about it?

18. Is there any material that magnetic lines of force will not pass through?

19. What is a solenoid coil?

20. What is the difference between a fuse and a magnetic circuit breaker?

VOLTAGE AND RESISTANCE

Your study of the lessons which follow will provide you with:

1. A knowledge of voltage (emf) and how it causes current to flow in an electric circuit.

2. An understanding of how and why emf must be maintained in order to cause a continuous current flow, and a working knowledge of how this emf or voltage is measured.

3. The ability to determine the proper voltage to be used on electrical equipment designed to operate with a certain amount of current flow.

4. An understanding of what resistance is, factors controlling resistance, how resistance is measured, and how it controls current flow.

Directions:

1. Use the study-help questions as a guide to your study.

2. Become familiar with all new words, terms, and definitions in order that you can carry on an intelligent conversation with your fellow workers.

3. Study additional information in the various reference materials recommended by your instructor.

4. Keep your notebook up to date with sketches, terms, and notes on the material you are studying.

Study-help questions:

1. What causes current to flow in an electrical current?

2. What is voltage?

3. What is meant by emf? How many different methods may be used to produce emf? Which method is the most important in your work?

4. What is the name given the instrument used to measure voltage? How must this instrument be connected in a circuit?

Lesson 1-1-7
WHAT CAUSES CURRENT FLOW

Required reference:

Electricity One-Seven,

Additional information:

EMF: Electromotive force or potential may be thought of as analogous to hydraulic pressure in water pipes. Electricity will always flow, or try to flow, from points of higher potential to points of lower potential. Hydraulic pressure causes water to flow through a system of pipes. Electric potential or voltage will cause an electric current to flow along a wire or conductor which provides a closed circuit. Voltage is always measured as the difference in electrical pressure or potential between two points. If the difference of potential between two points is great, there will be a strong tendency to produce a flow of current between them. If their potentials are equal, there will be no current flow.

The earth has been arbitrarily taken as having zero potential, but since the earth, even though a good conductor, has some resistance, as do all conductors, all points on the earth's surface may not be at exactly the same potential. It is for this reason that power stations are provided with the best ground grid that is economically feasible to limit the rise in ground potential when large amounts of current may be flowing through the earth due to faulted power lines or insulation failure on power equipment.

Check-up: (1-1-7)

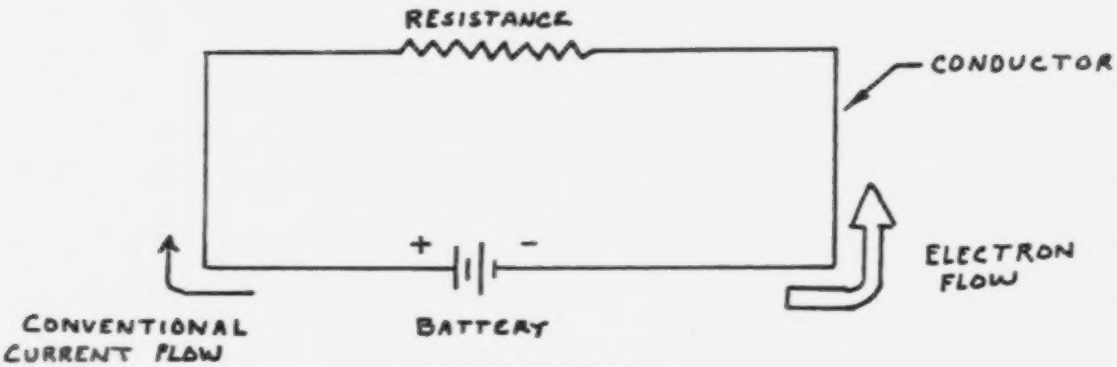
1. Of the six different sources of electricity, which ones are used most frequently to supply voltage for the use of electric power?

2. What are the three basic elements of an electrical current?

3. State the conditions necessary to have current flow in a circuit?

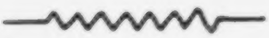
4. Can voltage exist without a complete electrical circuit?

5. What effect does voltage have in controlling current in a circuit?

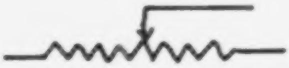

RESISTANCE
CONDUCTOR
+
-
ELECTRON FLOW
CONVENTIONAL CURRENT FLOW
BATTERY

SIMPLE CIRCUIT

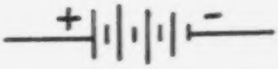
SCHEMATIC ELECTRIC SYMBOLS



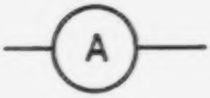
Resistor



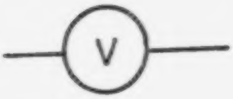
Variable Resistor



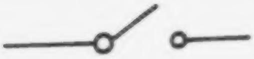
Battery (The Long Line Is Always Positive)



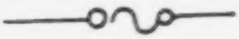
Ammeter



Voltmeter



Single Pole Single Throw Switch



Fuse

Lesson 1-1-8
RESISTANCE

Required reference:

Electricity One-Seven,

Additional information:

Thus far we have not mentioned anything about the resistance of various materials, but every substance possesses resistance in varying amounts. Materials like glass, rubber, and porcelain offer very high resistance to the flow of electric current. This resistance is in the order of millions of ohms, or megohms (ohms times 1,000,000). Such materials as silver, copper, aluminum, and iron possess such small resistance that we must sometimes express their resistance in milliohms (ohms divided by 1,000) or microhms (ohms divided by 1,000,000).

Materials which possess very high resistance are called insulators while those materials which have relatively small resistance are called CONDUCTORS. In general, good conductors of heat are good conductors of electricity, while poor conductors of heat are relatively poor conductors of electricity.

The resistance which a material offers the flow of electricity is referred to as the RESISTIVITY of the material. Resistivity is the resistance of a given size and shape of a material under standard conditions. For example, a unit frequently used is ohm-cm or microhm-cm (the resistance of a one centimeter cube expressed in ohms or microhms). Resistivity of typical materials includes:

Hard rubber--from 10^{14} to 10^{16} ohm-cm (varying with humidity)

Glass--from 10^{11} to 10^{15} ohm-cm

Copper--1.724 microhm-cm

Silver--1.628 microhm-cm

Aluminum--2.828 microhm-cm

Iron--9.96 microhm-cm

So we see glass and porcelain being used as insulators while copper, aluminum, and other metallic substances are used as conductors.

Circular Mil. The circular mil is the cross-sectional area of a wire whose diameter is equal to 1 mil (0.001 inch). The area in circular mils is equal to the square of the diameter of the wire in mils (thousandths of an inch). Thus a wire of 10 mils (0.010 inch) diameter would have a cross-sectional area of 100 circular mils.

Wire Tables. If you will refer to page 617 of Basic Mathematics for Electronics, you will find a table showing the allowable current-carrying capacity of various insulated conductors. Wire gages are arbitrary standards for the measurement of diameters of wire. The standard in the United States is the American Wire gage shown here. This table is based on a room temperature of 25-degrees centigrade, as temperature affects the current-carrying capacity of wires. This will be taken up later. Wire tables may show the current-carrying capacity for bare copper installed on a pole line in the air, widely separated from other conductors carrying current. In this case, No. 8 AWC wire would have a current-carrying capacity of approximately 90 amperes, which allows for a 50-degree centigrade rise in the temperature of the conductor. The National Electrical Code table shown on page 735 of the *Electrical Metermen's Handbook* shows the allowable current-carrying capacities for several types of insulation and governs the installation of wires inside buildings.

Temperature and Its Effect on Resistance. As stated before, the resistance of a conductor depends on its temperature. For every degree rise in temperature above some given point, each ohm of resistance is increased a constant amount, A, which denotes the coefficient of temperature of resistance. The temperature coefficient of resistance for copper at zero degrees centigrade is 0.00427. The relation between resistance and temperature may be expressed by equation $R = R_o \ (1 + A \ )$

Where R = resistance at temperature of degrees centigrade

R_o = resistance at zero degrees centigrade

A = temperature coefficient of resistance at zero degrees centigrade

= temperature in degrees centigrade

Negative Temperature Coefficient. The conductor carbon acts just the opposite from copper in that its resistance lowers as the temperature is increased, so we say that it has a negative temperature coefficient. You will have use for carbon in your work as a meterman, in the form of discs or blocks stacked together to form a compression rheostat. A carbon rheostat will carry relatively large currents and operate at considerably above-normal temperatures.

Check-up: (1-1-8)

1. Does every substance possess resistance to the flow of electric current?

2. Would you use glass as a conductor of electricity? State the reason for your answer.

3. A copper conductor having a diameter of 128.5 mils has a resistance of 0.64505 ohms per 1,000 feet. What resistance would it have if it had a diameter of 460 mils?

4. What are materials having a very low resistance called? What is the name given to materials having a very high resistance?

5. No. 18 copper magnet wire has a resistance of 34.3728 ohms per mile. What is the resistance of 1,000 feet of this wire?

6. The resistance of a copper wire, at zero degrees centigrade, is 12.5 ohms. What will the resistance of this wire be at 45 degrees centigrade?

7. The resistance of a copper wire, at 20 degrees centigrade, is 6 ohms. What will the resistance of this wire be at 30 degrees centigrade?

8. Silver has a resistivity of 1.628 microhm-cm. Is it a better or poorer conductor of electricity than copper? Why?

9. Porcelain has a very high resistivity at ordinary temperatures. Will this material make a good insulator?

10. Iron has a resistivity of 9.96×10^{-6} ohm-cm. Will iron make as good a conductor of electricity as aluminum? Please give the reason for your answer.

11. How do you tell the values of resistors?

12. What is an ohm?

13. In terms of ohms, how much resistance is one megohm? One microhm? One kilohm? One milliohm?

14. What is a rheostat? A potentiometer?

15. What is meant by the tolerance of a resistor?

Lesson 1-1-9
ALGEBRA REVIEW

Required reference:

Basic Mathematics for Electricity and Electronics,

Additional information:

Algebra is a written language or shorthand in which the sentences are called formulas or equations. Letters and symbols are used to represent definite electrical quantities with which the meterman, wireman, and technician will come in contact every day. Unless you have or acquire an understanding of some of the simple operations of algebra, you will be severely handicapped in learning the fundamentals of electricity. This course does not pretend to teach a course in algebra, but a short review of the fundamentals will point up any shortcomings the student may have.

Check-up: (1-1-9)

Addition (find the sum of):

1. 37, -67, 96, 105, -3
2. $a^2 -2ab +b^2$
3. $$\begin{array}{l} 3x -5y -8 \\ \underline{3x +5y -8} \end{array}$$
4. $6x -7a$, $4a$, $4x +10a +17$
5. $3x + y$, $7x -2y$, $5x +4y$
6. $-3ax$, $14ax$, $-25ax$, $19b$, $16ax$

Subtraction:

7. From $6xy -13h$ take $10xy -4k$
8. From $a^2 +2ab +b^2$ take $a^2 -2ab +b^2$
9. From the sum of $3a^2 -2ab +b^2$ and $4a^2 -5ab -b^2$ take $4a^2 -5ab -7b^2$
10. From $8x^2 -10y^3 +11z^3 -12xyz$

    take $-13x^2 +14y^3 -15z^3$

Multiply:

11. $(x^3)(x^4) =$
12. $(a^2)(a^3)(-a^4) =$
13. $(3a^2)(4b) =$
14. $(4x +7z)(6r) =$
15. $(7ax^3 -21ab^4 -3x^2)(2a^2b^3x^4) =$

When it is desirable to consider as a single quantity an expression involving several numbers or symbols, the expression is enclosed in a parenthesis. This parenthesis may then be used in operations as if it were a single number, as in fact it is, excepting that the operations inside the parenthesis may not yet have been performed and the result simplified. In working problems involving signs of grouping, the operation within the parenthesis should be performed first.

Some rules to remember: When a single parenthesis is preceded by a plus sign (+), the parenthesis may be removed, the various terms retaining the same signs. When a single parenthesis is preceded by a minus sign (-), the parenthesis may be removed, providing we change the signs of all the terms inside the parenthesis.

When several parenthesis occur in an expression remove, the innermost parenthesis, changing the signs of the terms inside if the sign preceding it is minus. Simplify, if possible, the expression inside the new, innermost parenthesis.

16. $(A + 1)^2 =$ 17. $(x + 6)(x + 7) =$

Simplify the following by removing the signs of grouping and uniting the like terms:

18. $2a + 5b - (a + 4b) =$ 19. $10y - 10 - (-3y + 4) =$

20. $a - (b - (a + 4) =$ 21. $m - (3m - 2 + p) - m - n + p =$

22. $x - 2y + 3z - (2x - 3y + 4z) - (-3x + z) =$

23. $17 - (2 + (3 - 7) =$ 24. $2x - (3x - (x-y) - y) =$

25. $19 - 3 - (4 - (-6 + 10) =$

Divide:

In the last few years small, portable, battery-operated electronic calculators have become most popular with engineers, technicians, students, and all sorts of people who are required to do mathematics or calculations. As with the slide, these devices are available in a large variety of price ranges. Calculators are available that will perform most any function commonly used in the solution of electrical problems. They, of course, have many advantages over a slide rule, being much more accurate, and most will automatically place the decimal point. The better calculators have rechargeable batteries, are fully portable, easy to operate, and not only can perform addition, subtraction, multiplication, division, squares and square roots, but will operate with numbers in scientific notation (powers of ten). If one wishes to spend the money, a calculator that is programmed for trigonometry is a time saver when making calculation for A-C circuits.

This author believes that the serious student will benefit more from this course of study if one will procure a calculator as very few people actually enjoy performing mathematical calculations. When one must spend hours adding, subtracting, multiplying, or dividing to obtain an answer, the solution of simple problems can be exceedingly tedious and we are mainly interested in the answers. When the student has a device to assist him in arriving at the answer, the calculations of these problems actually become enjoyable, particularly when the solution is proving or illustrating one of the basic concepts of electricity.

On the next page you will find a few examples to practice on. You can test your ability with a calculator by checking your answer against the answer given.

EXAMPLES FOR CALCULATOR PRACTICE

Multiplication and Division

1. $\frac{11 \times 402}{32} = 138$

2. $\frac{14 \times 525}{47} = 156$

3. $\frac{24.5 \times 43.4}{3620} = 0.294$

4. $\frac{1.35 \times 3.16}{6.2} = 0.688$

5. $\frac{2.28 \times 0.0125}{4.36} = .00654$

6. $\frac{7.63 \times 2.34}{24.3} = 0.735$

7. $\frac{2.56 \times 1.78}{7.4} = 0.615$

8. $\frac{82.5 \times 9.3}{56.5} = 13.6$

9. $\frac{32.6 \times 22.1}{9.25} = 77.9$

10. $0.64 \times 32 \times 5.6 = 114.7$

11. $16.3 \times 1210 \times 3.65 \times 243 = 17{,}490{,}000$

12. $\frac{5.42}{2.42} = 2.24$

13. $\frac{7.35}{3.14} = 2.34$

Square Root

14. $\sqrt{4.50} = 2.12$

15. $\sqrt{1.68} = 1.29$

16. $\sqrt{20.50} = 4.53$

17. $\sqrt{19000} = 137$

18. $\sqrt{32400} = 180$

19. $\sqrt{593.50} = 24.3$

20. $\sqrt{108.8} = 10.4$

21. $\sqrt{0.084200} = 0.290$

LESSON 1-1-10
EQUATIONS

Required reference:

Basic Mathematics for Electricity and Electronics,

Many problems that are solved by means of algebra involve the equation in one form or another. It is only through an understanding of the equation that one gains the ability to change a formula to other forms that are more convenient for certain computations. This makes the equation the most important tool of algebra. Some equations are very easy to solve; but in many cases, the solution of an equation is by no means a simple matter. The practical solution of equations depends on the application of the axiom that states: If equal numbers be added to, subtracted from, multiplied by, or divided by equal numbers, the results are equal. In multiplying or dividing both sides of an equation by a literal expression which involves the unknown, it should be observed that the resulting equation may have the solution which the original equation did not possess. The solutions of equations involve most of the other mechanics of algebra.

Check-up: (1-1-10)

Solve for the value of x in the following equations:

1. $5x - 8 = 2x + 7$
2. $8x + 3 = 3x + 13$
2. $4x + 3(2x - 4 (x - 2) = 72 - 6x$
4. $6x + 8 - 23x = 16x - 3$
5. $7(2x - 6) - 8 = 10x + 10$
6. $2x - 3 = 3x - 7$
7. $4x - 10 = 2x + 2$
8. $300x - 250 = 50x + 750$
9. $2.5x + 0.5 = 1.5x + 1.5$
10. $4(4x - 6) + 2(2x - 3) = 5(2x - 6) - 10$

Solve for the unknown:

11. $16 - (2y - 3) = 2y + 3$
12. $10 - (E - 2) - E = -27 + (E + 3)$

If F stands for number of degrees Fahrenheit scale and C for the number of degrees Centigrade:

$C = \frac{5}{9}(F - 32)$ And $F = \frac{9}{5}C + 32$

13. $176^{\circ}F$ = ? in C 14. $24^{\circ}C$ = ? in F 15. $55^{\circ}C$ = ? F

36

Lesson 1-1-11

PROBLEMS INVOLVING RESISTANCE AND WIRE SIZES

Required references:

Basic Mathematics for Electricity and Electronics, Fifth Edition,

Electricity One-Seven,

Check-up: (1-1-11)

1. In wire measure: (a) what is a mil? (b) what is a circular mil? (c) what is a mil-foot?
2. What is the circular mil area of a wire 0.289 inch in diameter?
3. What is the diameter of a wire containing 1,024 circular mils?
4. What is the diameter of a wire containing 83,690 circular mils?
5. What area in circular mils will a circle having an area of 2.65 square inches have?
6. A rectangular bus bar 1/4-inch thick by 4-inches wide would have how many circular mil?
7. What is the resistance of 10 miles of copper wire 1/2 inch in diameter?
8. What size wire (B & S) will have a resistance of practically one ohm per 1,000 feet?
9. What wire, American gage should be used to transmit electric power 2 miles (2 miles out and 2 miles back); resistance should not exceed 2.7 ohms, temperature at 20 degrees centigrade?
10. How many miles of No. 00 wire will it take to make 8 ohms?
11. What is the resistance of 500 feet of No. 14 copper wire at 25 degrees centigrade?

12. What size wire will have a resistance of practically one ohm per 1,000 feet?

13. A relay has a coil that measures 150 ohms resistance. The coil has 750 turns of about 6 inches in average length. What size wire is the coil wound with?

14. What size will an aluminum wire be which has the same resistance as a No. 4 copper wire? (Where K is the ohms resistance of one mil-foot of the kind of wire used, L is the length of the wire in feet, and C.M. is area of the wire.)

Hint: $R = \frac{K \times L}{C.M.}$

Note: The ohm/mil-foot of aluminum is = 17

15. Find the resistance of 1,000 feet of No. 4 aluminum wire.

16. No. 8 copper wire has a resistance of 0.641 ohm per 1,000 feet. What is the resistance of two miles of this wire?

17. A square conductor that is 0.50 inch on a side has a resistance of 0.004 ohm. Another square conductor that is 0.25 inch on a side is of the same material and the same length. What is the resistance of the second conductor?

18. The resistance of a power line wire constructed from No. 0000 aluminum was measured and found to be 0.96 ohm. If No. 0000 aluminum has a resistance of 0.0804 ohm per 1,000 feet, find the length of the wire.

19. No. 2 copper wire, which has a diameter of 0.258 inch, has a resistance of 0.840 ohm per mile. What is the resistance of 800 feet of No. 6 wire which has a diameter of 0.162 inch?

20. It is desired to install a conductor to carry 40 amperes. what size copper wire should be used?

Lesson 1-1-12
PROBLEMS INVOLVING RESISTANCE AND TEMPERATURE

Required references:

Basic Mathematics for Electricity and Electronics,

Electricity One-Seven,

Check-up: (1-1-12)

1. The field-magnet winding of a 230 volt dc generator has a resistance of 34.0 ohms at 20 degrees centigrade. Find the resistance of the winding, which is copper, when the temperaure rises to 55 degrees centigrade.

2. The resistance of the secondary of a transformer was 2.50 ohms at 20 degrees centigrade. After the transformer had operated under full load for 6 hours, the resistance of the secondary was measured and found to be 2.99 ohms. What was the final operating temperature?

3. The resistance of a copper wire is 6.4 ohms at 10 degrees centigrade. What is it at 75 degrees centigrade?

4. The cold resistance (20 degrees centigrade) of an armature was 3.64 ohms. The hot resistance was 4.86 ohms. What was the temperature rise?

5. How does the icrease of temperature effect the resistance of all pure metals?

6. What is the length of a 250 pound coil of No. 12 wire?

7. What is the temperature coefficient of resistance?

8. The primary coils of a transformer has a resistance of 5.48 ohms at 30 degrees centigrade. After a run of 4 hours, the resistance has risen to 6.32 ohms. What is the temperature rise of the coil?

9. Certain substances, notably carbon, porcelain, glass, certain semi-conductors such as geranium and metal oxides, decrease in resistance very rapidly when heated. Their temperature coefficient is said to be what (positive or negative)?

10. Alloys with zero temperature coefficients can be compounded. That is, the resistance of conductors composed of these alloys remain practically constant at all ordinary temperatures. Their temperature coefficients are 0.0. Judging from what you have learned from this lesson, do you think such an alloy would make a good remote temperature detector?

ELECTRICAL THEORY

UNIT II
DIRECT-CURRENT CIRCUITS

This unit contains the following lessons:

D-C SERIES CIRCUITS

Lesson 1-2-1: Ohm's Law and Series Circuits
Lesson 1-2-2: The Mathematics of D-C Circuits

D-C PARALLEL CIRCUITS

Lesson 1-2-3: Electric Power - Rate of Doing Work
Lesson 1-2-4: D-C Parallel Circuits
Lesson 1-2-5: Ohm's Law Applied to Parallel Circuits

D-C SERIES - PARALLEL CIRCUITS

Lesson 1-2-6: Voltage, Current, and Resistance in Series-Parallel Circuits
Lesson 1-2-7: Voltage-Divide and Distribution Circuits
Lesson 1-2-8: Kerchoff's Laws Applied to Complex Circuits

D-C SERIES CIRCUITS

The lessons which follow are intended to give you:

1. An understanding of the various factors necessary in order to have a complete electrical pathway (circuit).
2. A knowledge of the characteristics that distinguish a d-c series from the other types of d-c circuits.
3. The ability to solve elementary problems by the use of formulas and a working knowlege of Ohm's Law as applied to series circuits.
4. An understanding of the symbols and terms used in the established rules or formulas for elementary circuits.

Directions:

1. The study-help questions should be kept in mind as you study.
2. This unit is presented on a progressive basis. Therefore, you should thoroughly understand each topic before taking up those which follow it. Write out and hand in to your instructor the answers to all check-up questions. Where problems are involved, show your work.
3. Enter in your notebook, diagrams of series circuits found in your study material and in your work on the job.

Study-Help Questions:

1. The old fashioned string of Christmas tree lights would fail to burn if any one of the bulbs were faulty. Why is this so?
2. Can you explain why the resistance of a series circuit is equal to the sum of the individual resistances?
3. What is a "short" circuit? What are some of the common causes?
4. What is an "open" circuit? A "closed" circuit? What are some of the devices and methods used when it is desirable to open and close circuits? What are some of the courses that open a circuit when it is not desirable?
5. How did Ohm's Law applied to d-c series circuits?
6. Why is the current in all parts of a series circuit the same?
7. Why is the commercial use of series circuits limited?

Lesson 1-2-1
OHM'S LAW AND SERIES CIRCUITS

Before undertaking the study of d-c circuits, it is important that you take the time to understand thoroughly what a circuit is. In any electrical circuit, it should be clearly established that electrical energy must have a certain pressure (emf--volts) in order to accomplish anything. The resistance offered to the flow of electrical energy along a length of some conduct-material is an important related factor.

Required reference:

Electricity One-Seven,

Check-up: (1-2-1)

1. What constitutes an electric circuit?
2. Explain in your own words the difference between an "open" and "closed" circuit.
3. What is the primary function of a switch in an electric circuit?
4. State Ohm's Law. What are the three ways this law may be written?
5. What are the units of the following and define each:

   a. Electromotive force (E)
   b. Current (I)
   c. Resistance (R or)?

6. What symbols do we use for the following: (a) amperes, (b) volts, (c) ohms, (d) potentiometer, (f) fixed resistor, (g) rheostat, and (e) watts?
7. Of what does a series circuit consist?
8. What is the total resistance, R , or R_1, R_2, R_3, and R_4, connected in series?
9. How does the voltage divide among the various resistors connected in a series circuit?
10. In a series circuit what is the value of the current in any part of the circuit in terms of the total current?

11. What is meant by "voltage drop"?

12. What constitutes a "short circuit"?

13. How do series power sources affect current?

14. What are some of the causes of an "open circuit"? How can you find where the circuit is open?

Lesson 1-2-2
THE MATHEMATICS OF D-C SERIES CIRCUITS

Required reference:

Basic Mathematics for Electricity and Electronics,

Check-up: (1-2-2)

1. How much resistance does a resistor have if 1 ampere flows through it when 10 volts are applied across it? Show your work.

2. What amount of current will flow if you apply 100 volts to a 100-ohm resistor?

3. A voltmeter across a resistor reads 50 volts and an ammeter in series with the resistor reads 1.5 amperes. What is the value of the resistor?

4. What voltage is necessary to force 2 amperes through a 20-ohm resistor?

5. An electric iron draws 5 amperes from a 120-volt line. What is the resistance of the iron?

6. A current of 1 milliampere flows through a 2,000-ohm resistor. What is the voltage applied to the resistor?

7. What is the voltage across a resistance of 1 megohm when 2 milliamperes flow through it?

8. A buzzer requires 150 milliamperes at 1.5 volts to operate it. How much resistance does it have?

9. If a 1-milliampere maximum-rated milliammeter having a resistance of 27 ohms is connected across a 12-volt battery, how much current will it draw? What will happen to the milliammeter?

10. If a 1-ampere maximum-rated ammeter having a resistance of 79 milliohms in series is connected with a load consisting of 12 ohms, and a voltage of 120 volts is applied across the 12-ohm load and the ammeter, what will happen to the ammeter? How much current will it draw?

11. From the disastrous results obtained in problems 9 and 10, what is your general conclusion regarding the use of ammeters? How should they always be connected in a circuit? Should the resistance of the load be checked before applying the ammeter to the circuit? If so, why?

12. If a voltmeter having a resistance of 1940 ohm is connected in series with a load consisting of 60 ohm and requiring 120 volts to operate it, what will be the result?

13. From the results obtained in problem 12, what are your conclusions as to how a voltmeter should be connected in a circuit?

14. Given three resistors of 2 ohms, 5 ohms, and 10 ohms, respectively, connected in series, what is the total resistance of this combination?

15. Eight lamps, 30 ohms each, are connected in series and 120 volts is applied to this series circuit. (a) What current flows through each lamp? (b) What voltage would appear across each lamp?

16. Two wires lead from a pole to a house. The resistance of each wire is 0.35 ohm. When the current is 50 amp and the voltage between wires at the pole is 124 volts: (a) How much voltage drop is there in the line (both wires combined)? (b) What is the voltage between wires at the house?

17. If the current is only 10 amp in the same line described in question 16: (a) How much voltage drop in the line? (b) What is the voltage between the wires at the house?

18. A 10-ohm resistor is connected in series with another resistor of (unknown substance) to a 120-volt source. The voltage measured across the 10-ohm resistor is 48 volts. (a) How much current flows in each resistor? (b) Find the resistance of the second resistor?

19. A switchboard lamp requires 400 ma to make it glow. The hot resistance is 312 ohms. What pressure is required?

20. An electromagnet has a resistance of 65 ohms. It will lift a certain load of iron when the current through it is 5 amp, but will not drop the load until the current is reduced to 3.5 amp. What voltage is required: (a) to lift, and (b) to release the load?

D-C PARALLEL CIRCUITS

You are to acquire from your study:

1. A knowledge of what electric power is and an understanding of the various related factors such as units of electric power, power rating of equipment, and how equipment is protected by fusing.
2. An understanding of d-c parallel circuits and connections--how resistance affects current flow through the parallel branches of the circuit and how voltage across each resistance is affected.
3. An understanding of the symbols and terms used in the established rules or formulas dealing with parallel circuits.
4. The ability to solve elementary problems by the use of Ohm's Law when applied to parallel circuits.

Directions:

1. Study the references as directed. Write out and hand in to your instructor the answers to all check-up questions. Use the study-help questions as a general guide to your study.
2. Ask your shop foreman and class instructor to assign typical, practical problems that will give you a greater opportunity to master procedures and techniques needed to solve parallel-circuit problems.
3. Have your instructor or shop foreman check all of your problems and answers until you have gained experience and confidence in making calculations.

Study-help questions:

1. How does a parallel circuit differ from a series circuit?
2. In a parallel circuit why is the voltage rating the same when applied to each resistance and when connected across a voltage source?
3. Why does current flow divide unequally in different types of electrical equipment connected in parallel?

4. How do you determine the total resistance of equal resistances connected in parallel?

5. How do you determine the total resistance when unequal resistances are connected in parallel?

6. Why is a knowledge of algebra so helpful in acquiring an understanding of electric circuit problems?

Lesson 1-2-3

From the previous assginment you have learned what factors are necessary in order to have an electrical circuit. You have also learned how Ohm's Law is applied to simple and series circuits. Before studying other types of d-c circuits, take the time to become familiar with what electrical power is and how it is measured.

Required reference:

Electricity One-Seven,

Check-up: (1-2-3)

1. Define "power" and give its symbol.

2. What is the basic unit of power? What does this unit equal in terms of voltage and current?

3. Give the two variations of the power formula using Ohm's Law.

4. Why are appliances such as lamps, irons, soldering irons, and resistors, rated in watts?

5. If two resistors, one having a resistance of 18 ohms and the other having a resistance of 7 ohms, are connected in series, and a voltage of 15 volts is applied to the circuit: (a) how much power is being used in each resistor, (b) what is the total wattage being used?

6. The 7-ohm resistor in problem 5 is a 10-watt unit and the 18-ohm resistor is rated at 2 watts. What will happen to the resistors in this problem?

7. One horsepower is equal to 746 watts and this is often used in the rating of an electric motor. What would the rating in kilowatts be if a motor is rated at 50 horsepower?

8. The resistance of a 600-volt voltmeter is 69,120 ohms. What amount of power is used when the voltmeter is connected across 480 volts? Show how you would check this.

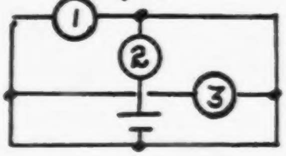
9. What is the rating in horsepower of a motor which draws 46.625 amperes from the line at 480 volts. Expressed in kilowatts, what is the rating of this motor?

10. What is a fuse? How is it used?

BRIGHTEST LIGHT QUIZ

In each of the circuits (A-J) below, all of the bulbs have the same voltage and current rating. Because of the way in which they are connected, however, one bulb in each circuit lights up brighter than the others. Can you find it? Check the bulb you think is the bright one.

(A)



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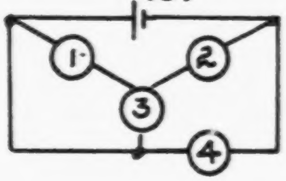

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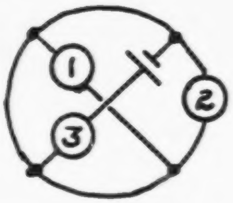

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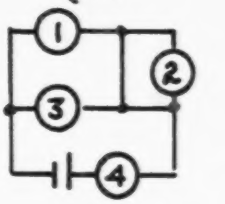

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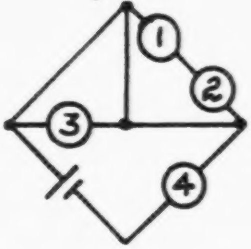

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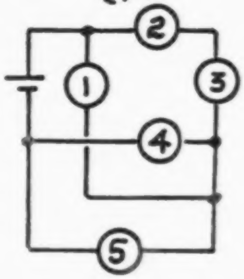

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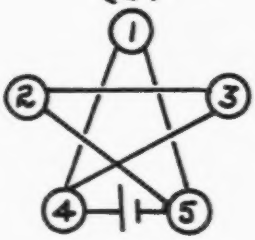
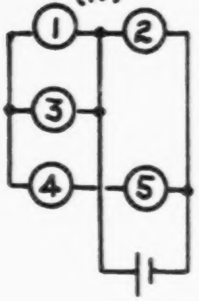
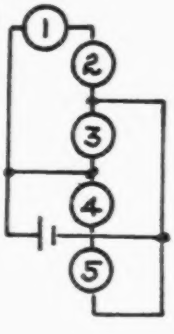


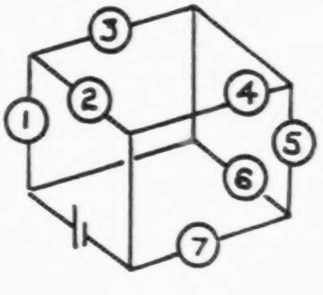
(H)



(I)



(J)



(A) ______ (B) ______ (C) ______ (D) ______ (E) ______

(F) ______ (G) ______ (H) ______ (I) ______ (J) ______

For answers, see page 49

Lesson 1-2-4

D-C PARALLEL CIRCUITS

Required reference:

Electricity One-Seven,

Check-up: (1-2-4)

1. Is the total resistance of two resistors connected in parallel more or less than the value of the smallest resistor?

2. Explain how the current flows in a circuit having two unequal resistances connected in parallel. Two equal resistances.

3. If we have N numbers of resistors of equal value connected in parallel, how do we find the total resistance of the circuit?

4. What is the combined resistance of four 100-ohm resistors connected in parallel?

5. What is the formula for finding the total resistance of two unequal resistors connected in parallel?

6. What does the voltage equal, in terms of the total voltage, across each resistor in the circuit when the various resistances are connected in parallel?

7. What does the current equal, in terms of the total current, across each resistor in a circuit when the various resistances are connected in parallel?

8. Must all of the resistors connected in parallel in a circuit have the same voltage rating such as an electric razor, a vacuum cleaner, a dryer, and a water heater?

9. You will remember the formula for finding the total resistance of a number of resistors connected in parallel:

   From this formula please develop the formula for finding the total resistance of any number of resistors connected in parallel: R = ?

10. Supply the missing words: In a parallel circuit, the same ______________ is applied to each branch. The total current is equal to the sum of the ____________ in the individual branches, and the effective resistance is equal to the applied _____________ divided by the total __________; it is always _____________ than the lowest resistance in the circuit.

11. A lamp is marked 125 volts and 200 watts. What current does it require?

12. What is the resistance of a 400-watt toaster which is made for use on a 120 volt circuit?

13. (a) Compare the power (watts) used by a 29-ohm heater when operated on a 240-volt line; and (b) When operated at one-half voltage (i.e., on a 20 volt line).

14. Four lamps of equal voltage and power rating are connected in series across a 440-volt line. The current through the lamps is 0.909 amp. (a) What is the power expended in each lamp? (b) How much is the resistance of each lamp when this amount of current is flowing?

15. (a) A 20,000-ohm resistor is rated 10 watts. What is the maximum current it can carry without exceeding its 10-watt rating? (b) What is the maximum voltage that could be dropped across this resistor without exceeding its 10-watt rating?

16. A 12-volt battery is charged at a 5-amp rate for 24 hours. How many KWH of energy is put into the battery?

17. (a) A motor takes 5 amps on a 120-volt line. Find the horsepower output. (b) Find the KWH of energy consumed if this motor runs continuously for 24 hours. (c) Find the cost of operating the motor if energy costs two cents per KWH.

18. A 120-volt power supply is connected to three resistors connected in series. The first resistor is 5 ohms. An ammeter indicates 6.2 amp of current flowing in this series circuit. If the voltage across the third resistor is 62 volts: (a) What is the value of R_2? (b) How much power is expended in the circuit?

19. In one test on heating a house by electricity it was found that it required 3.6 KWH per year to heat one cubic foot of space. At one and one-half cents per KWH, what would it cost to heat a house containing 12,000 cubic feet?

20. If a 1,000-ohm, 10-watt resistor is connected across a 120-volt source, would the resistor overheat? Show why.

Lesson 1-2-5
OHM'S LAW APPLIED TO PARALLEL CIRCUITS

Required reference:

Basic Mathematics for Electricity and Electronics,

Check-up: (1-2-5)

1. What is the combined resistance of 15 ohms, 10 ohms, and 5 ohms connected in parallel?

2. Four 5-ohm resistors are connected in parallel in a circuit having 5 volts impressed across it. (a) What is the total resistance? (b) How much current will flow in each resistor? (c) What is the total current in the circuit?

3. What is the combined resistance of 5, 10, 20, and 15 ohms connected in parallel?

4. What is the combined resistance of: (a) three 50-ohm resistors in parallel, (b) four 50-ohm resistors in parallel, (c) five 50-ohm resistors in parallel?

5. What is the combined resistance of 125, 250, 500, and 1,000 ohms connected in parallel?

6. We have two resistors connected in parallel: their values are 10 ohms and 15 ohms. If we cut the total resistance in half, what value of resistance will the third resistor have? How much current will flow in each resistor when we apply 15 volts to the arrangement?

7. If 90 volts are applied to the circuit in problem 6:

   (a) How much current will flow in each resistor when only the first two resistors are connected?

   (b) How much total current will flow under these conditions?

   (c) How much current will flow in each resistor when we add the third resistor to the circuit?

   (d) How much total current will flow in the circuit with all three resistors connected in parallel?

8. How much power is being used in each of the three resistors under the conditions of problem 7?

9. How much current will flow in each resistor in problem 1 when we apply 45 volts to the circuit? What is the total power being used in the circuit with 45 volts applied to it?

10. In problem 1 we wish to cut the resistance down to a value of one-third, that obtained with 15, 10, and 5 ohms. How much will the value of the fourth resistor be when connected in parallel with the other three resistors?

11. Three resistors are connected to a 120-volt line. Total current is 12 amps. One resistor is 20 ohms, one is 30 ohms. Calculate the ohms for the third resistor.

12. When a resistor of 80 ohms is connected in parallel with a resistor of 120 ohms, what is the total resistance?

13. Three resistors are in parallel: one is 250 ohms, one is 300 ohms, one is 150 ohms. The 250-ohm resistor has a current of 60 ma. Calculate the current in the other two resistors, and the total current in the line.

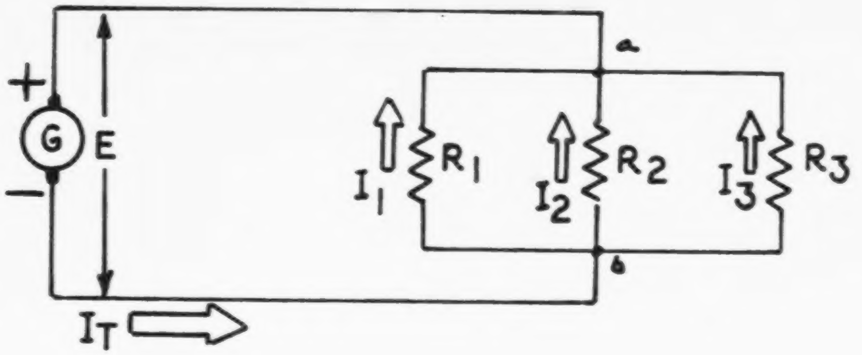
14. Find the total resistance of: (a) Two 1,000-ohm resistors connected in parallel, (b) Four 1,000-ohm resistors connected in parallel.

15. A 4-ohm, 8-ohm, 12-ohm, and 16-ohm resistor is connected in parallel. Calculate the combined resistance of this parallel group.

16. How much power would be expended in each of the parallel connected resistors in question 15 if this group is connected across a 120-volt source?

17. Four resistors of 8,000, 1,500, 2,500, and 3,000 ohm are connected in parallel. What is the equivalent resistance of the combination?

18. What resistance must be connected in parallel with a 20-ohm resistance to create a 4-ohm equivalent resistance?



19. In the circuit shown above, R_1 = 16 ohms, R_2 = 4 ohms, I_3 = 4 amp, and E = 32 volts. Find (a) I_t, (b) I_1, (c) I_2, (d) R_3, (e) total power.

20. In the circuit shown above, if R_1 and R_2 are both 10,000 ohm resistors, and R_3 is a 5,000 ohm resistor; the total current is 0.40 amp. What value of resistance must be connected between junctions a and b to result in a total current of 0.50 amp?

Answers To Brightest Light Quiz:

Answers (A) 2
(B) 4
(C) 3
(D) 4
(E) 4
(F) 1
(G) 4
(H) 2
(I) 3
(J) 4

D-C SERIES-PARALLEL CIRCUITS

You are to acquire from the lessons that follow:

1. An understanding of how various combinations of series and parallel circuits can be arranged to make up the two basic types of series-parallel circuits.

2. A knowledge of how to use formulas to find the total resistances connected in series-parallel.

3. An understanding of how current flows and how voltage divides in a series-parallel circuit.

4. A working knowledge of Kirchhoff's Laws and how they are used to simplify complex circuit problems.

Directions:

1. Study additional references and make it a point to observe circuits and their components.

2. Make sketches of the various types of circuits and use arrows to show the direction of d-c current from the source to the load and back to the source. In this way you will be able to fix the three common types of circuits in mind.

3. Write out and hand in to your instructor the answers to all the check-up questions. When problems are involved, show your work.

Study-help questions:

1. What are the basic types of series-parallel circuits?

2. Why are no new formulas needed to find the total resistances connected in series-parallel?

3. The total circuit current depends upon what important factor when connected across a voltage source?

4. What voltage drops occur in a series-parallel circuit?

5. What two general rules make the solution of any part of a complex circuit easy?

6. Can Kirchhoff's Laws be used to determine unknown resistances in a complex circuit?

7. Briefly explain Kirchhoff's First Law; Kirchhoff's Second Law.

Lesson 1-2-6

VOLTAGE, CURRENT, AND RESISTANCE IN SERIES-PARALLEL CIRCUITS

Required references:

Electricity One-Seven,

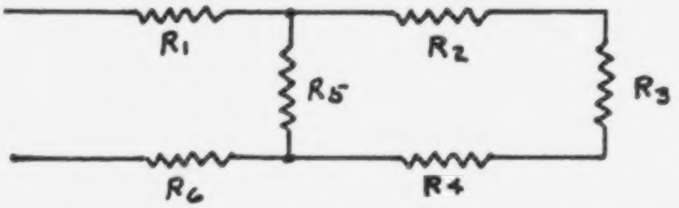
Basic Mathematics for Electricity and Electronics,

Check-up: (1-2-6)

1. Name the steps that you would follow in determining the total resistance of a complex series-parallel circuit.

2. Explain why no new formulas are necessary in order to find total resistance in a series-parallel circuit.

3. Find the total resistance of the following arrangement of resistors, assuming that each resistor has a value of 1 ohm.



4. Find the total resistance of the following arrangement of resistors, the value of the resistor being:

R_1 = 7 ohms

R_2 = 4 ohms

R_3 = 3 ohms

R_4 = 2 ohms

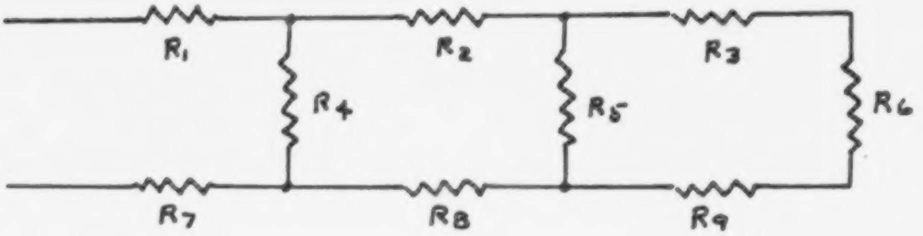
R_5 = 15 ohms

R_6 = 5 ohms

R_7 = 9 ohms

R_8 = 8 ohms

R_9 = 2 ohms



5. Upon what factor does the total current flow in a series-parallel circuit depend?

6. What value of current does the sum of all of the branch currents equal in a series-parallel circuit?

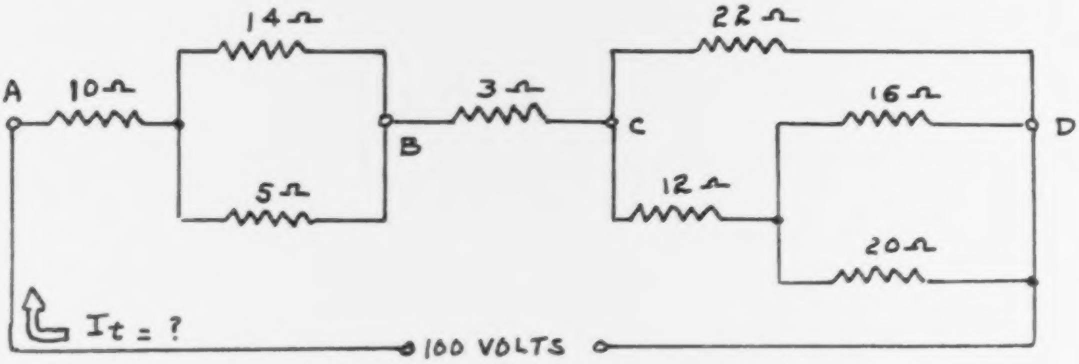
7. What does the total voltage across a series-parallel circuit equal in terms of the voltage drops in the various paths between the two ends of the circuit?

8. Two resistances: $R_1 = 150$ ohms, $R_2 = 200$ ohms, are connected in parallel and this parallel combination is connected in series with a third resistor which equals 620 ohms. If 230 volts is applied to this series-parallel combination: (a) What is the total current of the circuit? (b) How much power is expended in R_2?

9. In the series-parallel combination in question 8: (a) If R_3 is short circuited, how much power will be expended in R_1? (b) What will be the total current, if R_1 is open circuited?

10. In a series-parallel circuit, a single resistor R_1 equals 5,600 ohms and is connected in series with a pair of parallel resistors R_2 and R_3. When a 1,000 volt power supply is connected across this series-parallel combination, 29.3 ma of current flows through R_2. If R equals 7,180 ohms, find the (a) voltage across R_1, (b) voltage across R_2, (c) total current, and (d) total power expended in the circuit.

11.

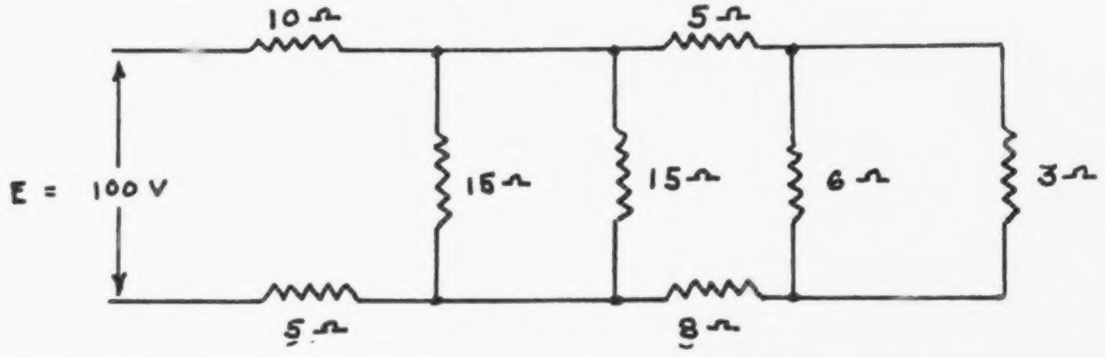


Find the total current.

12. Find the total current if C and D were short circuited.

13. How much power is expended in the 3-ohm resistor in problem 11, if A and B are short circuited?

14. Reduce the series-parallel circuit shown below to an equivalent series resistor:



15. Determine the amount of power that would be expended in the series-parallel circuit shown for problem 14.

Lesson 1-2-7
DETERMINATION OF RIGHT SIZES FOR WIRES

Required references:

Electricity One-Seven

Basic Mathematics for Electricity and Electronics

In deciding upon wire sizes which should be used in any part of any distribution system, it is necessary to determine accurately the current which each must carry. The size in each section must be such that the current does not exceed the amount given in the Bureau of Standards - National Electric Code. An electric current heats any conductor through which it passes. If heat is generated in the wire faster than it can be dissipated from the surface of the wire, the resulting high temperature will cause the insulation to deterioate.

The voltage drops throughout the system should also be determined. A drop of 10 percent may be allowable in some cases, however, low voltage has a bad effect on the speed of motors and a drop of five percent will cause a noticable reduction in the amount of illumination given from incandescent lamps. Wherever excessive drops are found, larger wire must be used.

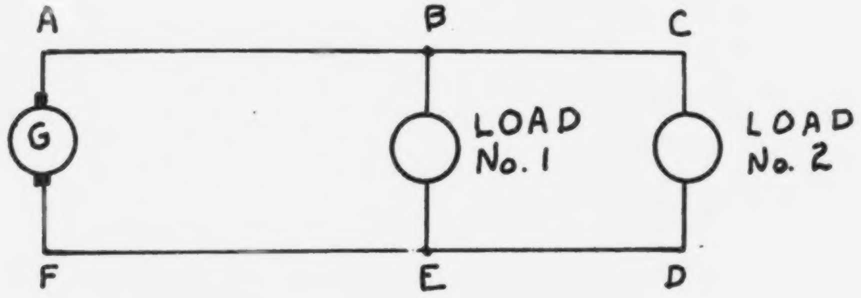
Stranded cables larger than 4/0 do exist and are rated directly in circular mils. For flexibility, stranded wire is used. Number 6 stranded has the same amount of copper, and the same current-carrying area, as No. 6 solid. Stranded wire is a collection of wires twisted together; for example, No. 18 lamp cord contains 16 No. 30 wires, loosely twisted together in the same direction.

Electrical conductors in high voltage transmission and distribution lines are usually made with copper or aluminum strands on the outside to carry the current, and with steel or copperweld on the inside to provide tensile strength. Current in conductors on a-c lines tends to flow in the outer part of the conductor and the center carries very little current due to a phenomenon called "skin effect", which you will learn more about later in the course. Because most of the current flows in the outside (or skin) of the conductor, the resistance of the core is not considered by the manufacturer in the resistance to a-c, and the circular mil cross section given in most tables is the cross section of the copper or aluminum only and does not include the steel core. Standard sizes range from 200,000 C.M. (200 MCM) to 5 million C.M. These cables may be bare or covered with any of a great variety of insulation materials.

Check-up: (1-2-7)

1. What will be the line loss in voltage and in watts per mile in transmitting 10 kilowatts at 240 volts if No. 00 wires are used?

2. In the circuit below, the distance from A to B is 200 feet, and from B to C is 150 feet. AB and EF are No. 6 wire, anc BC and DE are No. 14 wire. Load No. 1 draws 35 amperes and Load No. 2 draws 10 amperes. The generator develops 230 volts brush potential. (a) What is the voltage at Load No. 1? (b) Power lost in the lines is how much?



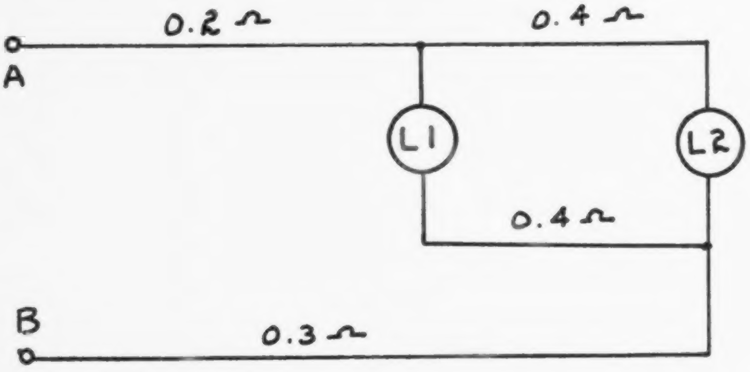
3. If in problem 2 the distance from A to B is 100 feet, and from B to C is 300 feet, AB and EF are No. 10 wire, and BC and DE are No. 14 wire, Load No. 1 requires 15 amperes and Load No. 2 draws 7.5 amperes from the generator which develops 120 volts brush potential, what (a) is the voltage at Load No. 1, (b) voltage at Load No. 2, and (c) power lost in the lines?

4. A No. 0 two-wire feeder was originally installed to carry a load of 100 amperes, but the load grew to 230 amperes. A repairman attempted to help the situation by paralleling the line with a feeder of No. 1 size. Both feeders were rubber-covered wire. Do the two feeders together have sufficient carrying capacity?

5. If we assume the lines to be 500 feet long in question 4 above, how many volts drop could be expected with that increased loading on parallel lines? How much power is expended in the line?

6. A generator with a constant potential of 240 volts is to supply power to a 12 kilowatt load one-half mile away. If not over 10 percent voltage drop is allowed in the line, what size wire must be used?

7. In the circuit below, L1 equals a load of 4 amperes, and L2 a load of 2.0 amperes. If the source voltage applied to points A and B is 120 volts, find (a) voltage across L1, and (b) voltage across L2.



8. A 2-horsepower d-c motor is to be installed on a 230 KV motor-operated disconnect switch. The motor draws 36 amperes at 48 volts when connected to its mechanical load. A 48-volt battery, located 100 feet from the motor, will be used to supply power to the motor. If it is desired to limit the voltage drop in the wires to not more than 2 volts: what size wire must be run from the battery to the motor?

9. If a 2-horsepower d-c motor, rated 125 volts, could be used for the 230 KV motor-operated disconnect in question 8, and the motor draws 14 amperes: what size wire could be used when a 125-volt battery is used to supply the power? Limit the voltage drop to no more than two volts.

10. Supply the missing words: For transmitting a specified amount of power, the line losses can be reduced by increasing the (a) ______________________________. (b) Power lost in the lines is due to the __________________ drawn by the load.

Lesson 1-2-8
KIRCHHOFF'S LAWS APPLIED TO COMPLEX CIRCUITS

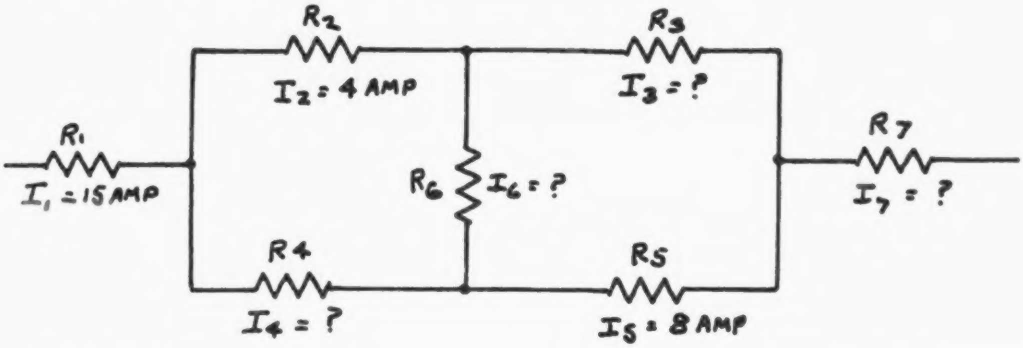
Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Check-up: (1-2-8)

1. In the sketch below are given the values of I_1, I_2, and I_5. Using Kirchhoff's First Law, which states that the algebraic sum of the currents at any junction of conductors is zero, find: I_3, I_4, I_6, I_7.



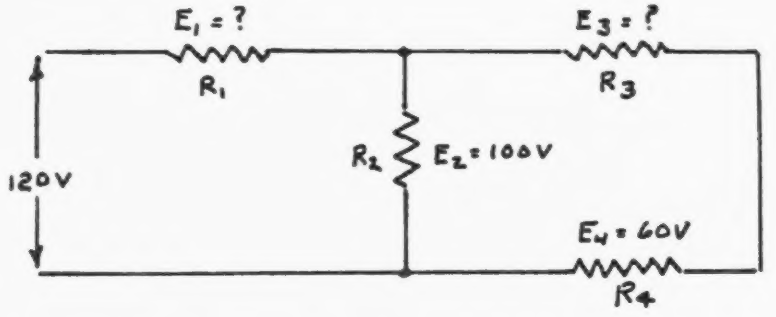
2. Solve both parts of the problem by Kirchhoff's Law:

   a. Kirchhoff's Second Law states that the algebraic sum of the electromotive forces and voltage drops around any closed electrical circuit is zero. If three resistors are connected in series across a voltage of 120 volts and the voltage drops of R_2 and R_3 are 10 and 15 volts, respectively, what is the voltage drop across R_1?

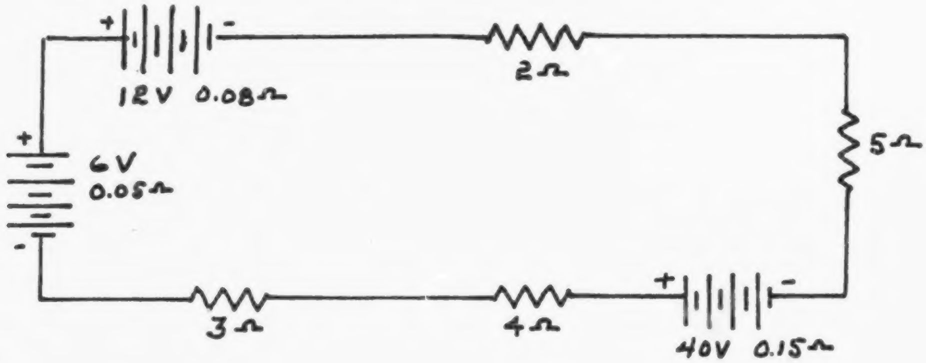
   b. Assuming that R_1 is equal to 50-2/3 ohms, R_2 equals 5-1/3 ohms, and R_3 equals 8 ohms, what is the value of current in the circuit?

3. Using Kirchhoff's Second Law, find the voltage drops across R_1 and R_3 in the following circuit diagram. The total

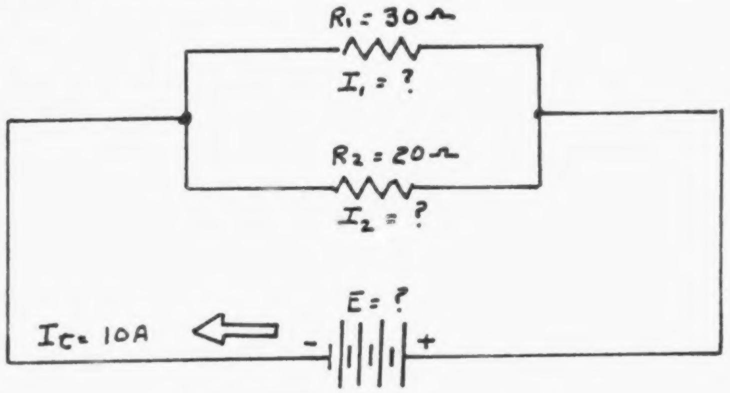
voltage is 120 volts and the voltage drops across R_2 and R_4 are 100 volts and 60 volts, respectively. (Hint: Reduce this diagram to its simplest form.)


E₁ = ?
R₁
E₃ = ?
R₃
120V
R₂
E₂ = 100V
E₄ = 60V
R₄

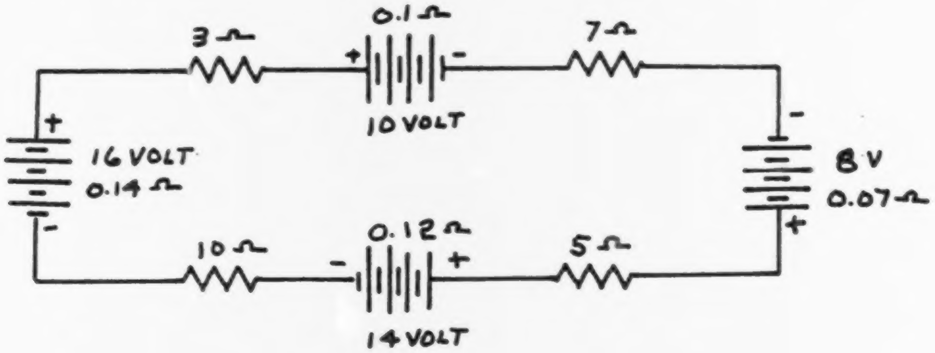
4. Kirchhoff's Second Law states that in a closed electrical circuit the sum of all voltage drops and the electromotive forces in that circuit equals zero. Applying this law to the following circuit, how much current flows?


+
-
12V 0.08Ω
2Ω
+
6V
0.05Ω
-
5Ω
3Ω
4Ω
+
-
40V 0.15Ω

5. A battery supplies 10 amperes to two resistors of 30 ohms and 20 ohms connected in parallel. If the internal resistance of the battery and the resistance of the connection leads is ignored, what is the battery voltage and how much current flows through each resistor?


R₁ = 30Ω
I₁ = ?
R₂ = 20Ω
I₂ = ?
E = ?
I_T = 10A
-
+

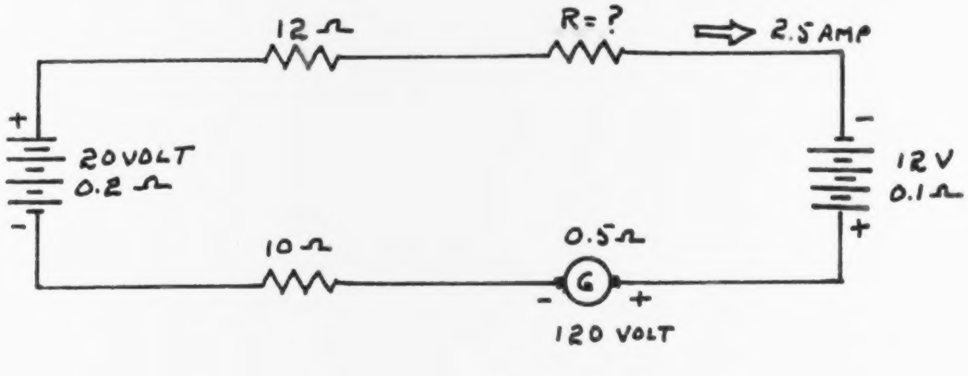
6. How much current will flow in the following circuit?


3Ω
0.1Ω
7Ω
+
-
10 VOLT
+
16 VOLT
0.14Ω
-
-
8 V
0.07Ω
+
10Ω
0.12Ω
-
+
5Ω
14 VOLT

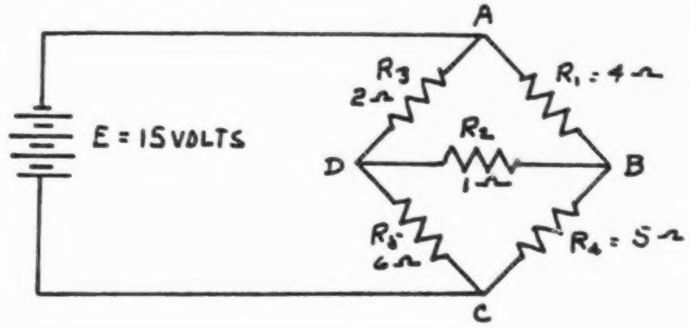
7. Three resistors: R_1 equals 2 ohms, R_2 equals 5 ohms, R_3 equals 3.6 ohms, and an unknown resistor, are connected in series across a 24-volt battery whose internal resistance is 0.1 ohm. If a current of 1.2 amperes flows in the circuit, what is the value of the unknown resistor? Prove this according to Kirchhoff's Second Law.

8. A 60-volt battery and a generator, with the positive of the generator connected to the positive of the battery, supply 7 amperes to two resistors connected in parallel. The values of the resistors are 15 ohms and 20 ohms. (a) What is the voltage of the generator? (b) What are the voltage drops of the resistors? (c) How much current flows in each resistor?

9. What is the value of R in the following circuit diagram?

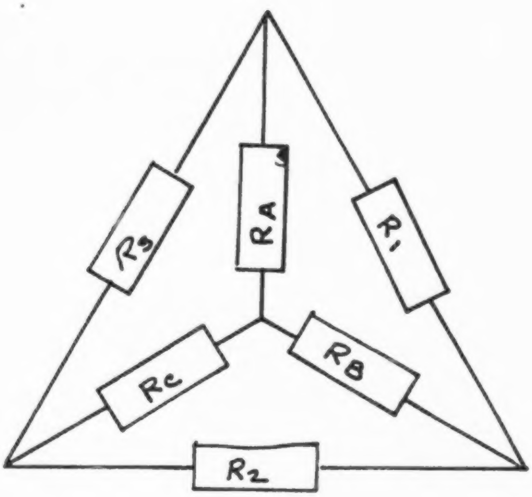

12Ω
R = ?
2.5 AMP
+
20 VOLT
0.2Ω
-
-
12 V
0.1Ω
+
10Ω
0.5Ω
G
-
+
120 VOLT

10. We have a network of resistors as shown below. (a) Find the equivalent resistance between points A and C. (b) How much current flows with 15 volts impressed across A and C?


A
R₃ 2Ω
R₁ = 4Ω
E = 15 VOLTS
R₂ 1Ω
D
B
R₅ 6Ω
R₄ = 5Ω
C

Note: An alternate solution to problem 10 is to use the equations for converting from a Delta Network to an equivalent WYE network.

Equivalent WYE from a Delta Network


R₃
RA
R₁
Rc
RB
R₂

$$R_A = \frac{R_1 \quad R_3}{R_1 + R_2 + R_3}$$

$$R_B = \frac{R_1 \quad R_2}{R_1 + R_2 + R_3}$$

$$R_C = \frac{R_2 \quad R_3}{R_1 + R_2 + R_3}$$

ELECTRICAL THEORY

UNIT III
ALTERNATING CURRENT

This unit contains the following lessons:

CHARACTERISTICS OF ALTERNATING CURRENT

Lesson 1-3-1:	Review of Mathematics
Lesson 1-3-2:	Check-Up Components of a Vector
Lesson 1-3-3:	Check-Up A-C Fundamentals
Lesson 1-3-4:	Check-Up

RESISTANCE AND INDUCTION IN CIRCUITS

Lesson 1-3-5:	Resistance in A-C Circuits
Lesson 1-3-6:	Inductance in A-C Circuits
Lesson 1-3-7:	Inductance
Lesson 1-3-8:	Mutual Inductance

CHARACTERISTICS OF ALTERNATING CURRENT

The lessons which follow will assist you in acquiring:

1. An understanding of why alternating current is preferred to direct current for electric power transmission.
2. A knowledge of important a-c characteristics and of a-c waveforms and their relationship to elementary generator operation.
3. The ability to use new terms when reading, studying, writing, or otherwise expressing ideas of your trade.
4. An appreciation of the importance of magnetic action in the genration, transmission, control, regulation, and utilization of electric current.

Directions:

1. Study the references thoroughly and make certain that you understand each theory and principle before advancing to the next topic. Familiarize yourself with all new words, terms, and definitions. Keep your notebook up to date.
2. Keep the study-help questions in mind while studying this assignment.
3. Answer all check-up questions after carefully considering the aim of the questions. When words alone fail to convey your meanings, make sketches, drawings, and diagrams.
4. Read the additional references that are assigned by your instructor.

Study-help questions:

1. Give several reasons why a-c is preferred over d-c for electric power transmission.
2. What is an elementary generator?
3. Make a sketch of a typical a-c waveform. What is this waveform called?

4. Describe the manner in which current flows in one cycle of alternating current.

5. What is your understanding of "superimposed a-c?"

6. What is meant by "frequency" when applied to alternating current?

7. Is 60-hertz alternating current universal in North America? If not, give one or two examples of two exceptions that you know about.

8. What is the term or name given to distinguish the maximum value reached twice during each cycle of a-c?

9. What is a transformer? How is it used in the transmission of electric power?

10. Why are a-c meters designed to read in "effective" voltage rather than in "peak" values?

Lesson 1-3-1
REVIEW OF MATHEMATICS

Required reference:

Basic Mathematics for Electricity and Electronics,

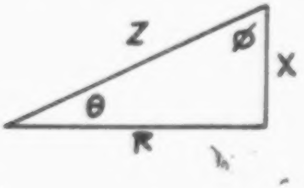
Additional information:

In the solution of problems dealing with a-c circuits it is often necessary to resort to the use of trigonometry, which is both algebraic and geometric in nature. Because a-c voltages and currents have both magnitude and direction, the resulting power produced depends upon the phase relationship between the voltages and currents.

Electric-circuit analysis is built around the idea that the voltages and currents be represented as vector quantities. An alternating current is one that alternates or changes its direction periodically and since the sine wave of an a-c is a periodic function, it can be represented as a rotating vector. Nearly all a-c circuits contain circuit elements, or components, that cause the voltage and current to pass through their corresponding zero values at different times. The effects of such conditions are given detailed coverage in many of the following lessons. Most of the electrical problems that need to be solved by a meterman can be resolved to the solution of right triangles. It is advisable at this time for you to review the trigonometric functions.

Check-up: (1-3-1)

Solve the following right triangles for the unknown elements:



1. R = 73.6, 0 = 15.0°
2. R = 425, 0 = 23.6°
3. X = 17.0, 0 = 69.1°
4. X = 38.0, 0 = 73.3°
5. Z = 70.0, R = 63.5
6. Z = 51.7, R =10.3
7. Z = 0.403, X = 0.290
8. Z = 48.7, X = 48.4
9. R = 8.10, X = 21.1
10. R = 454, X = 1,530

Lesson 1-3-2
VECTORS

Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Additional information:

The student will note that the solution to vectors by measurement with scale, protractor, and compasses is cumbersome and that the accuracy is definitely limited. If you are an apprentice meterman, or if you even expect to work in some of the more technical branches of the electrical trade, you should familiarize yourself with the trigonometric functions as applied to the solution of right triangles. You learned in Basic Mathematics for Electricity and Electronics the trigonometric ratios of acute triangles. The sine, cosine, and tangent ratios should be thoroughly memorized, and also how to use them. Finding the trigonometric function corresponding to a given angle can also be accomplished by using a calculator.

In Basic Mathematics for Electricity and Electronics, you learned the more precise mathematical method of solving for the horizontal and vertical component of a vector and vector addition of rectangular components. For the serious student who will use the mathematical method of solving a-c problems, the use of vector algebra and operator "j" will simplify the addition and subtraction of vectors.

In Volume 10 of Electricity One-Seven, you will come in contact with simple vectors which are certainly nothing to be afraid of. You will be solving some very difficult electrical problems by means of vectors. You will note the absence of complicated mathematics and that the only tools which you will need to solve these electrical problems are a ruler and protractor, plus a thorough knowledge of Ohm's Law as applied to alternating-current circuits.

One word of caution which you must follow in working electrical problems in this practical way is that you must construct your lines exactly to scale and your angles must be drawn exactly. If the lines and the angles are drawn exactly the answer will be correct. This method is usually only an approximation and you should learn how to apply the fundamentals of trigonometry to these problems to get correct answers in all instances.

From the very first you should make up your mind that you are going to understand vectors, what they mean, and how they are contructed. An understanding of these simple vectors is essential to a comprehension of diverse knowledge that is needed to work these assignments. It will pay you to study them long enough to thoroughly understand them. If you do not understand them, do not pass them up; stop right here and get help from someone who does understand them.

Electricity is a very difficult subject for the average person to visualize and to explain with the spoken or written word. In fact, the explanation of the various things which happen in an electrical circuit is practically impossible without the use of some such device as the vector diagram.

If you are an apprentice meterman, you will later have approximately one year's work with meter vectors which are extremely important to anyone working with meters. A journeyman meterman who understands vector diagrams is a much better meterman than one who does not have this knowledge. By means of vectors you can sove practically any metering problem quickly, easily, and accurately. You can determine the percentage of registration of a given watthour meter and any power factor of load, regardless of how many errors have been made in the connections. You can determine whether a watthour meter or a reactive kilovolt-ampere meter is properly connected. Without a complete understanding of the vector diagram, the solution of these problems is impossible.

VECTOR QUANTITIES

Since vector quantities are of considerable importance in the solution of problems in a-c theory, it is necessary that we become familiar with the algebraic method of performing the mathematical operations involving addition and subtraction with complex numbers.

There are two common algebraic forms for expressing a complex number, namely: rectangular and polar. It is most common to represent a vector by giving the length of magnitude of the quantity and the angle it makes with some reference axis. The reference axis is ordinarily assumed to be horizontal and to the right of the origin. The usual manner of expressing a complex quantity in polar form is as follows:

10 amp at an angle of 30 degrees is written: $10\angle 30^\circ$

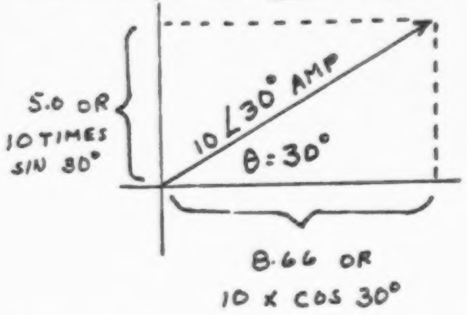
20 amp at an angle of minus 60 degrees: $20\angle 60^\circ$

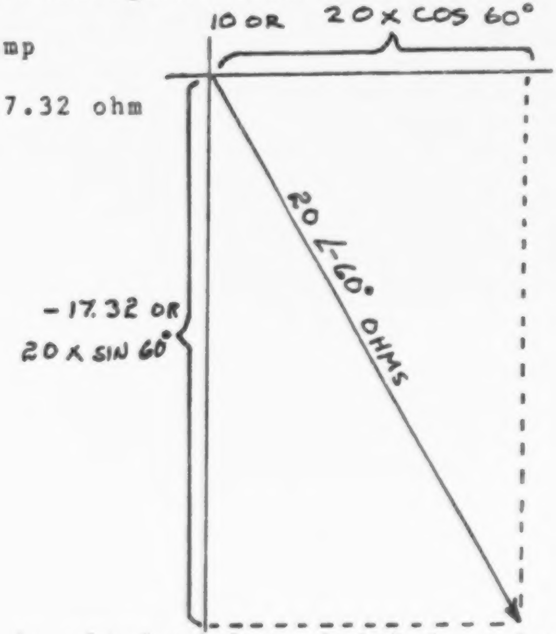
Where 10 amps is the magnitude of the vector and the 30 is the angle it makes with the reference or horizontal axis. Vectors may also be described in terms of their two components and this is most commonly accomplished through use of the operator j. A study of higher mathematics will show that the operator $j = -1$ (an imaginary number) but for our use in this course, all the student need be concerned with is that the operator j turns the vector through 90 degrees in a counter-clockwise direction from the reference axis each time it is used as a factor. In a similar manner a negative operator j, written -j, (rotates) turns the vector through 90 degrees in a clockwise direction from the horizontal reference.

Operator j therefore is used an an algebraic expression to describe the vertical component of a vector. The polar form of 10 30° amps then could be expressed in rectangular form as follows:

$10 \angle 30^{\circ}$ amp = 8.66 +j5 amp

similarly $20 \angle -60^{\circ}$ ohm = 10.00 -j17.32 ohm





10 = 10 (cos 30 +j sin 30)
 o = 8.66 +j5.0

20 = 20 (cos 300 +j sin 300)
 o = 10.0 -j17.32

Note that the horizontal component is obtained by multiplying the vector by the cosine of the angle of the vector and the vertical component is obtained by multiplying the vector by the sine of the angle of the vector.

Algebraic addition and subtraction of two vectors is accomplished easiest when expressed in its rectangular form. For example: add $5.4 \angle 31.5^{\circ}$ and $8.37 \angle -75.4^{\circ}$. Converting the vectors into their rectangular components in order to add or subtract them algebraically:

$5.40 \angle 31.5^{\circ}$ = 5.4 (cos 31.5) +j5.4 (sin 31.5)
= 4.6 +j2.82

$8.37 \angle -75.4^{\circ}$ = 8.37 (cos 75.4) -j8.37 (sin 75.4)
= 2.11 -j8.10

add 4.6 +j2.82
2.11 -j8.10
sum = 6.71 -j5.28: expressing the sum of the two vectors in

polar form: 6.71 -j5.28 = $8.54 \angle -38.2^{\circ}$

The student should work the examples just given and compare results. Alternating currents and voltages may be represented by complex expressions. Voltages and currents may be found where there is any angle between 0 and 360. For example: to find the complex expression for 100 volts at an angle of 30 degrees, 100 (cos 30 +j sine 30) = 86.6 +j50.0 volts.

Check-up: (1-3-2)

Find the horizontal and vertical components denoted by R and X, respectively, of the following vectors. Check the mathematical solution of each by drawing a vector diagram to scale.

1. 42.0 at 81.2°
2. 108 at 10.9°
3. 1.92 at 40.0°
4. 1,600 at 106.5°
5. 72 at 180°

Find the resultant forces of the following vectors:

6. 527 at 0° and 600 at 90°
7. 195 at 90° and 95.9 at 0°
8. 32.3 at 0° and 32.3 at 90°
9. 5.8 at 90° and 95.9 at 0°
10. 234 at 90° and 730 at 0°
11. Add 5.4 $\angle 31.5^{\circ}$ and 8.37 $\angle -75.4^{\circ}$ and express the sum in polar form.
12. Subtract 5.92 $\angle 51.3^{\circ}$ from 17.1 $\angle 32.2^{\circ}$ and express the result in polar form.

Lesson 1-3-3
A-C FUNDAMENTALS

Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Additional information:

You have seen how single phase alternating current is produced by magnetism. Referring to the diagrams on page 3-15 of Electricity One-Seven, if the coil of wire rotating in the magnetic field is producing 1 volt maximum, the voltage produced will be the sine of the angle through which the coil has moved. Thus at 0, 180, and 360 degrees, the voltage is zero; at 30 and 150 degrees, the voltage has risen to +0.5 volt; at 60 and 120 degrees, the voltage has reached +0.866 volt; at 90 degrees the voltage has become its maximum of +1 volt; at 210 and 330 degrees, the voltage is -0.5 volt; at 240 and 300 degrees the voltage has reached -0.866 volt; and at 270 degrees the voltage has attained its maximum of -1 volt.

Thus it is evident that the curve produced by the rotation of the coil is a sine wave and the voltage produced at any point along the curve equals E^m X sine 0, where E equals voltage and 0 equals the angle through which the coil has rotated.

Further, it will be noted that the line designated as "degrees of rotation" in the middle diagram on page 3-15 is proportional to time; that is, time progresses from left to right along this line. At 90 degrees, if the frequency is 60 (hz)*, the time is equal to 1/4 x 1/60 or 1/240 of a second. Likewise, when the voltage becomes zero passing to a negative value at 180 degrees, it is 1/2 x 1/60 or 1/120 of a second after the beginning of rotation. This is termed an ALTERNATION. At 60 cycles per second, it will be necessary for the loop of wire to make 60 complete revolutions per second. One complete revolution of the loop of wire equals 360 degrees and requires 1/60 of a second.

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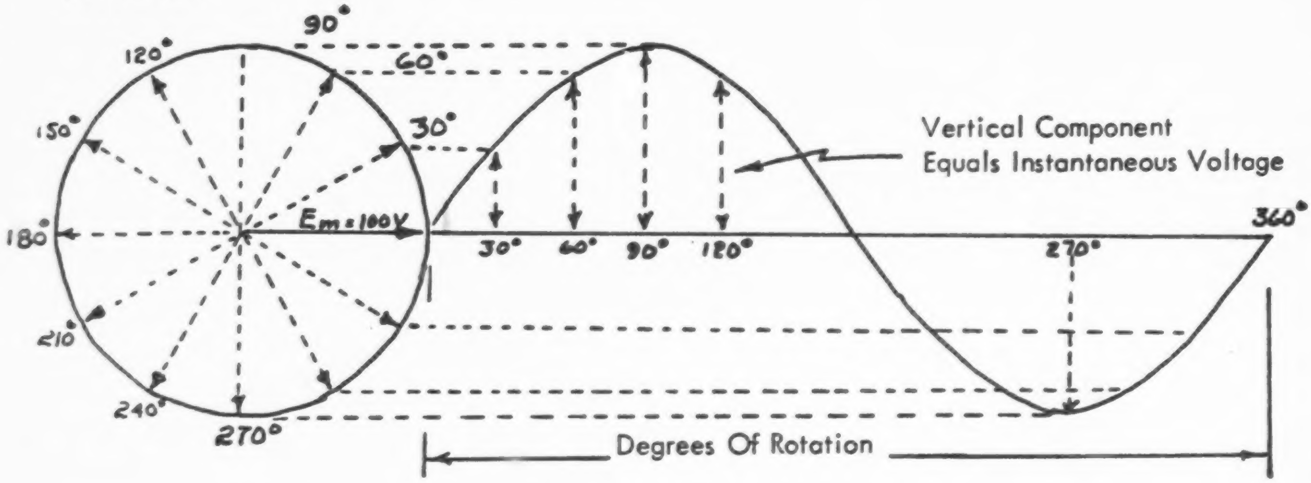
*Note: The term HERTZ (abbreviated hz) is being adopted as a substitute in place of cycles per second and, although your reference books may still use cycles per second, all future publications will, in all probability, use hz instead of cps.

Alternating voltage may be defined as an electromotive force which changes continously with time, rising from zero to a maximum value in one direction, decreasing to zero, and repeating these values at equal intervals of time.

An a-c voltage or current is often represented by a vector rotating about a point. The vertical component of such a vector is the instantaneous value of the voltage or current. The length of the vector is the maximum value of the voltage or current. If the vector shown below representing the magnitude of a voltage is plated against the number of degrees through which the coil of a generator has rotated, the graph obtained is called a sine wave. If the vector is rotated counter-clockwise, we show that the vertical component of such a vector is the instantaneous value of the voltage or current. The vertical height of any point on the sine wave is the product of the maximum value of the vector multiplied by the sine of the angle that the vector has rotated from its horizontal position. The angular position of the vector corresponds to the angular postion of a coil in a generator. The vector makes one complete rotation for each cycle of the a-c or current.

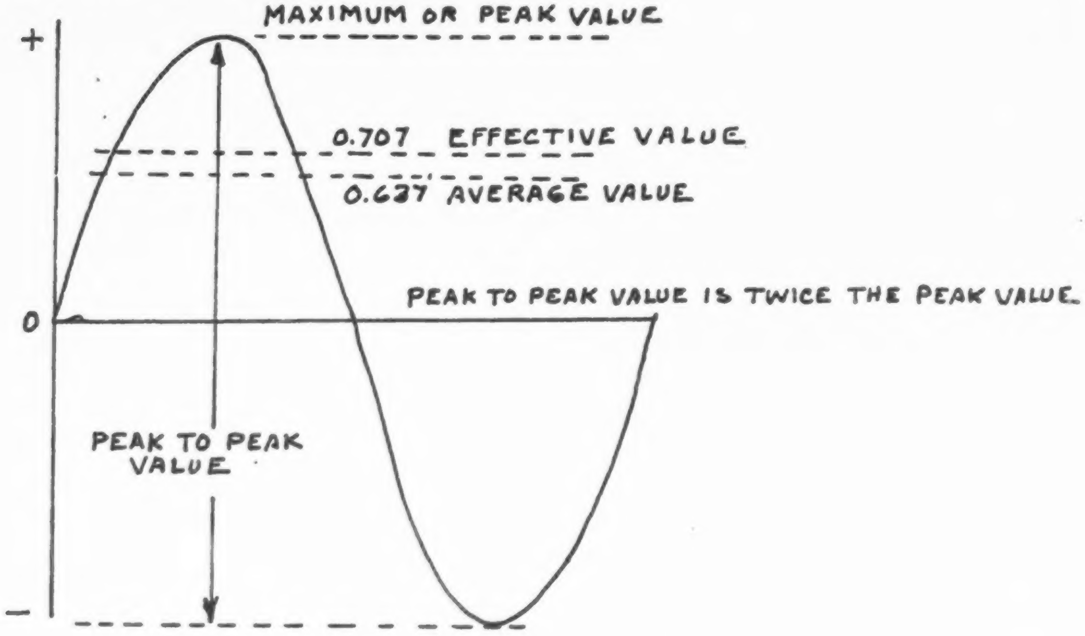


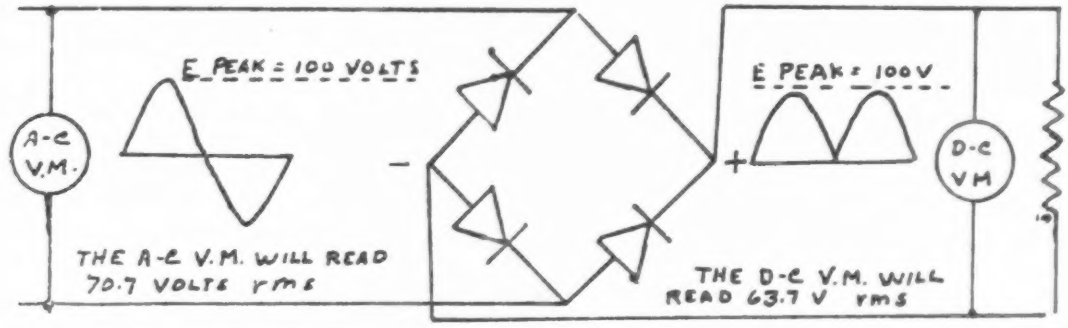
A Rotating Vector Can Represent A Sine Wave

If we assume the maximum value in the illustration is equal to 100 volts, the actual instantaneous voltage after 30 degrees of rotation is determined by: E instantaneous = E maximum times sine angle 30 degrees. The instantaneous voltage in this position is 100 x .5000 = 50 volts.

Vectors are always assumed to rotate counter-clockwise, unless noted otherwise. These vectors are used to represent current as well as voltage. An alternating current can be represented in the same way that the a-c voltage is shown here.

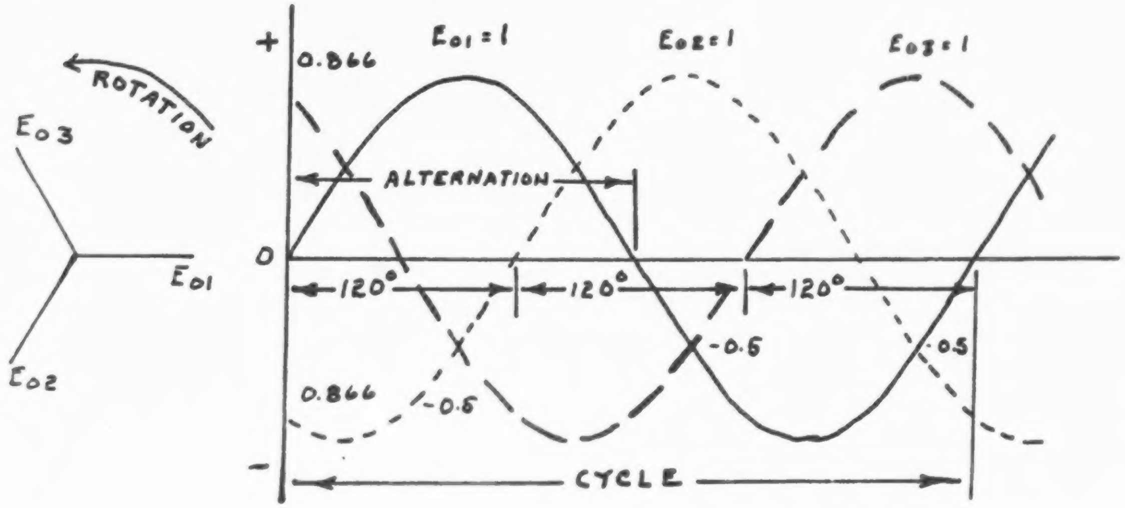
Since the magnitude (instantaneous value) of an alternating current changes from instant to instant, then the question is: "How do we measure the effective value?" The best method is to find the d-c current value which produces the same heating effect and, of course, will produce the same power. The product of effective volts and effective ampere equals the power in watts in any circuit containing a non-inductive resistance load. In practically all a-c work, effective or r.m.s. value of current and voltage are used. A-c voltmeter and ammeters are scaled to indicate the effective values which are 0.707 of the maximum values. In a steady d-c voltage supply, the effective and maximum values are the same.


MAXIMUM OR PEAK VALUE
+
0.707 EFFECTIVE VALUE
0.637 AVERAGE VALUE
PEAK TO PEAK VALUE IS TWICE THE PEAK VALUE
0
PEAK TO PEAK VALUE
–


E PEAK = 100 VOLTS
A-C V.M.
–
E PEAK = 100 V
+
D-C VM
THE A-C V.M. WILL READ 70.7 VOLTS rms
THE D-C V.M. WILL READ 63.7 V rms

There are some places where average value and peak-to-peak value have an application. Some of these are in electronic circuits and in semiconductors such as rectifier units using vacuum tubes or silicon rectifiers. For example, a full wave rectifier shown here will cause both alternations of the cycle to be in the same direction, but will produce a pulsating current, although it does not reverse direction. The effective value of this pulsating d-c current and voltage will be 0.637 of the a-c maximum or peak value which in reality is the average value for the two alternations.

Most of the problems which you will have as a meterman or wireman have to do with three-phase alternating currents and voltages, so it is well to know how three-phase alternating current is produced. Three-phase alternating current is produced in identically the same way that we have learned that single phase alternating current is produced. We simple replace the single coil with three coils spaced 120 degrees apart and rotate them in a magnetic field. This produces three separate and distinct voltages, 120 degrees apart, represented by three sine waves as shown in the diagram below:



In the above diagram, the voltage of E_{01} is zero at the start. As we start rotation, the value of E_{01} increases in a positive direction: 120 degrees later, E_{02} becomes zero and 120 degrees later E_{03} becomes zero. It will be noted that at any particular moment the sum of the three voltages generated is zero. For instance, at the point where E_{01} equals zero volts, E_{02} equals -0.866 volts and E_{03} equals +0.866 volts. Obviously, the sum of E_{01}, E_{02}, and E_{03} equals zero. Likewise, at the point where E_{01} attains a positive value of 1 volt (this point is 90 degrees after rotation has started) both E_{02} and E_{03} have reached a valne of -0.5. Again their sum equals zero and it is easily seen that this holds for any point in the cycle.

As the coils are shown connected in the diagram with all three coils connected together at 0, wires are taken off at E_{01}, E_{02}, E_{03}, and it is said to be in a three-phase, three- or four-wire, WYE connection. If the three coils are connected together in rotation and wires taken off at the three junction points, a three-phase, three-wire delta connection is formed.

The subjects of phase sequence and power factor in three-phase circuits will be discussed in detail later.

Check-up: (1-3-3)

1. Why do we use alternating current instead of direct current for the transmission of electric power?

2. What is the limiting factor in a transmission line? Is it conductor size, voltage, insulation, or what is it that limits transmission line capabilities?

3. What limits the amount of current that can be carried on a transmission line?

4. What is a cycle? What is an alternation?

5. What is the effective value of alternating current in percentage of the maximum value?

6. Alternating voltage is an electromotive force which changes continuously with time, rising from zero to a maximum value in one direction, decreasing to zero, rising to the same maximum value in the opposite direction, again decreasing to zero, and then repeating these values at equal intervals of time. What is a waveform of a current or a voltage made to represent? What kind of a waveform does alternating current or alternating voltage have?

7. What is frequency?

8. At 60 hz, how much time is consumed by the voltage going from 0 degrees to 270 degrees?

9. We use 60 hz in this country for our alternating current supply. Why do we not use a lesser frequency--say 10 or 15 hertz?

10. What is the maximum voltage in terms of the effective value of alternating voltage?

11. How does alternating current differ from a varying direct current?

12. Alternating current traces a curve called a "sine wave." What is a sine wave and why is it so called?

13. How many hertz equal 1,500 kilohertz? How many kilohertz equal 15,000 hertz?

14. Explain the difference between electrical and mechanical degrees.

15. What is meant by phase? Phase difference?

16. What is the effective value of a voltage whose maximum amplitude is 200 volts?

17. What is the rms value of a voltage whose peak-to-peak voltage is 200 volts?

18. What is the average value of the output voltage of a 6-volt battery? What is the rms value?

19. The voltage measured at a household electric outlet is 119 volts. This is the rms value of the voltage. What is the peak voltage? What is the average voltage?

20. One alternation of a sine wave take 4/1000 of a second. What is the frequency of the wave?

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Check-up: (1-3-4)

1. If a 4-pole generator is turned by a waterwheel at a speed of 1,800 rpm, what would be the frequency of the generator?

2. An alternator with 8-poles has a speed of 900 rpm, what frequency would it operate at?

3. If a 12-pole generator operates at a speed of 250 rpm, what would be the frequency of the generator?

4. A sine wave voltage produced by an a-c generator has a maximum value of 170 volts. Determine the instantaneous voltage at 45 electrical degrees after crossing the zero axis in a positive direction.

5. An alternator produces a maximum voltage of 325 volts. What is the instantaneous value of this voltage at 90 degrees? At 140 degrees?

6. Two a-c generators are to be operated in parallel at the same frequency. Generator No. 1 has 14 poles and turns at a speed of 1,800 rpm. Generator No. 2 has 10 poles. (a) What is the frequency of generator No. 1? (b) What is the speed of generator No. 2 so it may operate satisfactorily in parallel with generator No. 1?

7. What is the effective value of an alternating voltage whose maximum value is 311 volts?

8. Using the values obtained in question 7, what would be the instantaneous value for the voltage at 245 degrees?

9. If an alternating emf has the instantaneous value of 280 volts at 50 degrees, what is its value at 150 degrees?

10. What is the maximum value of an alternating current, if the instantaneous value at 310 degrees is minus 80 amp?

RESISTANCE AND INDUCTANCE IN A-C CIRCUITS

Your study of the lessons which follow will help you acquire:

1. The ability to determine when d-c rules and laws apply to a-c circuits.
2. An understanding of current, voltage, and power in a-c resistive circuits.
3. A number of terms and their definitions that help to explain inductive circuits and their properties.
4. An understanding of how power factor can be measured, adjusted, or corrected to meet various needs or conditions.
5. Further information as to the factors or conditions responsible for unbalanced circuits.

Directions:

1. Study the required references. Keep the study-help questions in mind as you progress.
2. Write out and hand in to your instructor the answers to all the check-up questions.
3. Read a number of references which will be recommended by your instructor. Do not depend on the required reference to give you the total picture.

Study-help questions:

1. Under what conditions do all d-c rules and laws apply to a-c circuits?
2. What is meant by "in phase" with regard to a-c voltages and currents?
3. What is meant by "power factor" in a-c circuits? What formula is used to find it?
4. What is the name of the instrument which is used to measure power? What basic principle or movement is used?
5. What factors cause the effect known as "inductance?" What is the symbol used to designate inductance? Does every complete electric circuit have some inductance?
6. List eight factors that will determine the amount of inductance in a circuit.

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7. What is meant by the term "mutual induction?" What is the most common electrical device used in your trade that utilizes this principle?

8. What is an "inductor?" Why are some inductors provided with a metallic shield?

9. How is power factor determined?

10. What conditions may cause a current to be out-of-phase?

Lesson 1-3-5
RESISTANCE IN A-C CIRCUITS

Required reference:

Electricity One-Seven,

Check-up: (1-3-5)

1. What are eddy currents? How are they related to frequency?
2. What is skin effect? Is it present in d-c circuits?
3. How is skin effect overcome in power cables? Why does this work?
4. What is the average power dissipated in an a-c circuit where the maximum voltage is 20 volts, and the maximum current is 40 amperes?
5. What is the average power dissipated in an a-c circuit where the effective voltage is 70 volts and the effective current is 30 amperes?
6. The instantaneous current through a resistor is 14 amperes and the instantaneous voltage across the resistor is 28 volts. What is the instantaneous power developed?
7. The peak value of the voltage in an a-c circuit is 100 volts, and the effective current is 7 amperes. What is the average power dissipated?
8. The peak power developed across a resistor is 1500 watts, when the effective voltage across the resistor is 500 volts. What is the average current over one alternation?
9. The average value of one alternation of a sine-wave voltage is 75 volts, and the peak value of the current is 3 amperes. What is the average power developed?
10. The average power developed across a resistor is 2000 kilowatts, and the peak-to-peak voltage is 200 kilovolts. What is the value of the effective current through the resistor?

Lesson 1-3-6
INDUCTANCE IN A-C CIRCUITS

Required reference:

Electricity One-Seven,

One of the basic principles you have learned is that a magnetic field surrounds every conductor or coil winding where there is a current, and that an increase or decrease in current will cause an increase or decrease in the number of lines of force of this magnetic field. This is true for d-c as well as a-c; however, by definition an alternating current is one constantly changing in magnitude and periodically changing in direction. A changing magnetic field induces a voltage in the coil, or circuit, proportional to the rate of change and in opposition to the effect producing the change. If the current in a circuit is increasing, the inductance of the circuit is defined as that property of the circuit which tends to prevent the increase; if the current is decreasing, the inductance of the circuit tends to prevent the decrease. The greater the inductance of the circuit, the greater the opposition to a change in current.

In a direct current circuit there will be no inductive effect once the current has reached its Ohm's Law value and remains constant. In a-c circuits there is ever present an opposition to the flow of current other than the d-c resistance of the circuit. This additional opposition is caused by a counter electromotive force. All elements in an a-c circuit, including the connecting wires, show some property to self induce or to generate this counter emf, but for all practical purposes only those elements designed to make use of this property have any significance, its effect is negligible in a circuit such as an electric lamp which uses almost pure resistance as a load.

Check-up: (1-3-6)

1. What properties, in addition to resistance, limit the current in an a-c circuit?

2. What rule gives the direction of the magnetic field around a current carrying conductor? State the rule.

3. For a conductor moving through a magnetic field, what rule gives the direction of the induced emf when the direction of the magnetic field is known? State the rule.

4. What factors determine the magnitude of the induced emf?

5. What is self induction?

6. On what two factors does the magnitude of a self-induced emf depend?

7. What is meant by counter emf? By back emf?

8. State Lenz's Law.

9. What determines the direction of the self-induced emf? How does Lenz's Law explain this?

10. How can self-induction be explained from an energy standpoint?

Lesson 1-3-7
INDUCTANCE

Required reference:

Electricity One-Seven,

Check-up: (1-3-7)

1. Define inductive time constant?

2. How many time constants does it take for the current to reach 63.2 percent of its maximum value in a d-c circuit?

3. In what units are time constants measured?

4. What is the total inductive reactance of three coils in series whose reactances are 5, 5, and 10 ohms?

5. What would be the total inductive reactance for the coils in Question 4 if they were in parallel?

6. What is the inductive reactance of a 10-millihenry coil at frequencies of 100 hertz, 1000 hertz, 10 kilohertz, 100 kilohertz, and 1 megahertz?

7. What is the phase relationship between current through, and the voltage across, an inductor? Why is this so?

8. What is the value of the time constant of a circuit consisting of a 5000-ohm resistor and a coil having an inductive reactance of 1.884 ohm at 60 hertz?

9. It takes 10 seconds for the current to drop to zero after the switch is opened in a d-c circuit consisting of a battery, switch, resistor, and coil. What is the circuit time constant?

10. If the value of the resistor of question 9 is 100 ohms, how many 40-henry inductors are needed to provide the inductance? Are they connected in series or in parallel?

Lesson 1-3-8
MUTUAL INDUCTANCE

Required reference:

Electricity One-Seven,

Check-up: (1-3-8)

1. What causes the emf of self-induction?

2. What is the effect of this emf of self-induction called?

3. What does inductance do to current that is increasing in a coil? To a current that is decreasing in a coil?

4. How may we increase the induced emf?

5. Is there any difference between the emf of mutual induction and the emf of self-induction?

6. A magnetic field or flux (circular lines of force) enshrouds every conductor through which electricity flows. Can mutual induction exist between two coils when there is no change in the current, that is to say, the current is direct current?

7. What occurs when the flux of one coil, called the primary coil, cuts the turns of the secondary coil? Explain how a current or emf can be generated in a circuit that is not even in electrical contact with the first circuit. Name one device which makes use of this principle?

8. Explain how energy may be transferred from one circuit to another using a battery, switch, meter, and two inductors.

9. What is the phase relationship between the currents that flow in two circuits that are mutually inductive?

10. What is the co-efficient of coupling between inductances?

ELECTRICAL THEORY

UNIT IV

ALTERNATING CURRENT

This unit contains the following lessons:

CAPACITANCE IN A-C CIRCUITS

Lesson 2-4-1: Capacitance in A-C Circuits
Lesson 2-4-2: Check-up
Lesson 2-4-3: Check-up
Lesson 2-4-4: Check-up

A-C SERIES CIRCUITS

Lesson 2-4-5: The Series RL Circuit
Lesson 2-4-6: R-C Circuits
Lesson 2-4-7: L-C Circuits
Lesson 2-4-8: LCR Circuits
Lesson 2-4-9: Series Resonance

A-C PARALLEL AND SERIES-PARALLEL CIRCUITS

Lesson 2-4-10: Characteristics of A-C Parallel Circuits
Lesson 2-4-11: Check-up
Lesson 2-4-12: Resonance in A-C Circuits

TRANSFORMERS:

Lesson 2-4-13: Basic Principles of Transformer Operation
Lesson 2-4-14: Classification of Transformers and Types of Construction
Lesson 2-4-15: Transformer Connections and Instrument Transformers
Lesson 2-4-16: Check-up

CAPACITANCE IN A-C CIRCUITS

You are to acquire:

1. Information pertaining to capacitance and capacitive reactance with regard to their effects in a-c circuits.
2. An understanding of how capacitors are made and operate, and how they are classified.
3. A working knowledge of the various symbols used to indicate types of capacitors.
4. A knowledge of some typical applications of capacitors in a-c circuits.

Directions:

1. Make a chart to help you remember various terms and definitions, especially when one is opposite to another in its influence upon a circuit or a current.
2. Picture each device and associate its properties and functions. Make sketches of the circuits in your notebook.
3. Study the required references and any additional references that may be assigned by your instructor.
4. Answer all check-up questions as they are designed to aid you in obtaining a better understanding of the various topics covered in the assignment.

Study-help questions:

1. Briefly explain the properties and action of capacitance in a circuit.
2. What similarity has capacitance to inductance?
3. What are the three basic factors that determine the capacity of a capacitor?

Lesson 2-4-1
CAPACITANCE

Required reference:

Electricity One-Seven,

Check-up: (2-4-1)

1. You will remember that inductance opposes any change in the circuit current. What is the opposition to any change in the circuit voltage called?
2. When does capacitance effect direct-current voltage?
3. What is the letter used to denote capacitance? What quantity of capacitance does this letter represent?
4. Upon what does capacitance depend?
5. If we apply direct current to a capacitor, how long does current flow?
6. If alternating-current voltage is applied to a capacitor, how long does the current flow?
7. Does alternating current actually pass through the insulating material between the capacitor plates?
8. What precaution should be taken when discharging a capacitor regardless of whether the voltage used to charge it is direct current or alternating current?
9. Using direct current, a capacitor is repeatedly charged and discharged. Each time it is discharged you note that the resulting arc or spark is the same size. If this charging and discharging of the capacitor with alternating current is repeated, the spark occuring at discharge varies in size and intensity. Explain why this is true.
10. How can you prove that capacitors block direct current? That capacitors appear to pass alternating current continuously?
11. What is a capacitor discharge?
12. Given a circuit consisting of a 100-milliampere alternating current milliammeter and a 1-microfarad capacitor in series, when 120-volts alternating current is applied, approximately 45 milliamperes will flow continuously. Explain this current flow in the face of the fact that the capacitor plates are separated with an insulating material.

Additional information:

Capacitors. There is a seemingly endless demand for capacitors of all sizes, types, and voltage ratings. There are literally thousands of each kind used yearly.

Capacitors are used extensively in the radio and television industries, and in the automobile industry. In fact, they are a vital part of practically all electronic circuits. Many sizes and various voltage ratings are used widely in direct current work. They are used in x-ray applications, particularly in industrial equipment. Capacitors for the purpose of starting motors are usually of the dry electrolytic type, as this particular type can be built economically in high microfarad capacitance for low voltage use.

Suppression of radio interference from motors and appliances of all kinds is accomplished through the use of capacitors. Coupling carrier current communications to high voltage lines, of all voltages, is accomplished with the coupling capacitor. Some voltage indicating devices are made with capacitors.

There is another field where capacitors are extensively used and which is not covered in the textbook. This is in the field of power factor improvement, either on power lines or in industrial plants on individual motors. The problem of power factor improvement is of very great importance to power companies. Capacitors are also used by power companies, either connected in parallel or in series, for voltage improvement.

Check-up: (2-4-2)

1. Describe the construction of a capacitor. What is the material which separates the plates called?

2. Name the factors which effect the capacitance of a condenser.

3. What is the dielectric constant of a capacitor?

4. Give the formula for two capacitors connected in series. What is the formula for two capacitors connected in parallel? In what way does this differ from connecting resistance in series or parallel?

5. Describe a variable air capacitor?

6. What precaution must be observed when using an electrolytic capacitor made to be used on direct current?

7. What will be the time constant in seconds of a 1-microfarad capacitor connected in series with a 2-megohm resistor?

8. What does the time constant equal?

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9. What three methods are used to identify capacitors?

10. How does voltage rating affect the size of a capacitor?

11. There are four capacitors: 2 mfd, 1 mfd, 0.5 mfd, and 0.25 mfd, connected in parallel. What is the total capacitance of this arrangement?

12. What is the total capacitance of four capacitors connected in series if the capacitance of the four capacitors is 6 mfd, 3 mfd, 4 mfd, and 1 mfd?

Capacitive Reactance. At the present time the use of small motors for household appliances such as freezers, refrigerators, washers, oil burners, and fans, and for air conditioning in homes and offices, has decreased the power factor of the electric feeders as the load has built up. The motors used on these devices generally have a rather low power factor, which means that the current consumed by them is high in comparison to the actual kilowatt load. The widespread use of induction motors and other inductive appliances, and the need for magnetizing current by line transformers, combine to draw greater line current than is required to supply only the actual power consumed. This greater current is due to the inductive (magnetizing) current which flows in the circuit as the magnetic fields build up and collapse during each cycle. The inductive current reaches its maximum value a quarter cycle (90 degrees) later than the voltage wave, and we say that the current lags the voltage by 90 degrees (see page 3-120 of Electricity One-Seven).

Capacitors draw a current which reaches its maximum a quarter cycle ahead of the voltage wave and the current is said to lead the voltage by 90 degrees.

In otherwords, capacitor current is 180 degrees out of phase, or exactly opposite to inductive or magnetizing current. Therefore, when a load consisting of both capacitive and inductive equipment is connected to a line, the inductive, or magnetizing, current between the generator and capacitor is reduced by an amount equal to the capacitive current. (You will learn more about this in later assignments.)

The line current multiplied by line voltage equals apparent power in volt-amperes, while the current supplying power multiplied by the line voltage gives the true power in watts. The ratio of watts to volt-amperes (watts/volt-amperes) is equal to the power factor of the circuit, as we have already learned.

An ideal situation for a power company is where it can deliver all of its current to loads having 100 percent power factor. Unfortunately, this condition does not exist and power companies must deliver energy to loads having a power factor ranging from 50 percent or less to between 90 percent and 100 percent. Usually these loads are of an inductive nature so that power factors of less than 100 percent are lagging power factors.

Some utility companies have a clause in their rates applying to power factor and their bills will be increased a certain percentage when the power factor falls below 80 or 85 percent. The bills will be reduced a certain percentage when the power factor exceeds a certain amount, which is usually 80 to 85 percent. The same thing is accomplished by other companies which charge a certain amount per unit of magnetizing current (called a kilovar) when the kilovar demand exceeds a certain percentage of the kilowatt demand. In any event, they install a meter to measure the amount of magnetizing energy.

If all of the current delivered by power companies were delivered at 90 percent power factor, then 10 percent of it would go to produce "wattless power." Out of every 100 amperes delivered by the power company, 10 amperes would go for wattless power and only 90 amperes would be utilized as useful energy. The power company would, therefore, receive pay for only 90 out of every 100 amperes.

Capacitors for the purpose of improving power factor are made exactly as described on page 3-100. The metal foil is usually aluminum, and the paper dielectric is impregnated with a refined mineral oil or some other liquid instead of wax. There are usually several thicknesses of paper for the higher voltage ratings. These units are made for 230, 460, 575, 2,300, 4,000, 6,900, 12,000, and 13,200 volts. They are rated in kilovolt-amperes, or kilovars, instead of in microfarads and are usually made in 5-, 10-, 15-, 25-, and 50-kilovar single-phase units housed in a metal container. The metal container is provided with a means for pole mounting and suitable bushings for connection to the line. The microfarad rating of these capacitors may be found as follows:

$$C \text{ (in microfarads)} = \frac{\text{Kilovars} \times 10^9}{2\ f \times (E)^2}$$

Thus for a 25 KVA capacitor for 2,350 volts:

$$C = \frac{25 \times 1{,}000{,}000{,}000}{6.28 \times 60 \times (2{,}350)^2} = \frac{25{,}000{,}000}{2{,}080{,}878} = 12 \text{ microfarads}$$

Example of Power Factor Correction. A certain bank of transformers is capable of delivering approximately 250 amperes at 240 volts, which amounts to slightly over 100 kilowatts at 100 percent power factor. There is a customer served from this bank of transformers who has 2.4 kilowatts in lighting at 100 percent power factor and 70-kilowatts motor load operating at approximately 70 percent power factor. Converting this load into amperes at 240 volts give us 10 amperes for lighting and 240 amperes for the 70-kilowatt load at 70 percent power factor, which makes a total of 250 amperes. We can see that this one customer has the bank of transformers fully loaded.

A request is received from a man living near this same transformer bank for delivery of 20 kilowatts of power at 240 volts and to be operated at 95 percent power factor. Such a load will require 50 additional amperes, making a total load on the transformers of 300 amperes. How much improvement must be made in the power factor of the 70-kilowatt motor load before we can safely add 20 kilowatts, or 50 amperes, to the transformers?

We will be able to draw: 250 - 10 - 50 = 190 amperes

Substituting in the formula for power, Watts = 1.732 x I x E x power factor, gives:

$$70{,}000 = 1.732 \times 190 \times 240 \times (\text{pf}) \text{ or pf} = \frac{70{,}000}{1.732 \times 190 \times 240}$$

Solving this equation we find that the power factor must be approximately 90 percent.

The small diary books put out by Westinghouse and General Electric each year have power factor improvement tables in them. From these tables we can ascertain what value of capacitors is required to improve the power factor of the 70-kilowatt motor load from 70 to 90 percent.

Looking up one of these power factor improvement tables we find under 90 percent (the desired power factor) and opposite 70 percent (original power factor) the number "0.536." Multiplying this number by 70 (which is out load in kilowatts) gives us 37.5 kilovars. If these 37.5 kilovars are connected in parallel as close as possible to the low power factor equipment, we can then connect the 95 percent power factor load of 20 kilowatts and the total load on the transformer bank will not be in excess of 250 amperes.

Check-up: (2-4-3)

1. How does a capacitor block d-c?

2. What are the voltage and current relationships between the capacitor and applied voltages? Between the capacitor current and applied voltage?

3. What happens to the capacitor current if the frequency of the applied voltage is decreased?

4. What is the opposition to the flow of a-c current offered by a capacitor called? What are its units?

5. What is the equation for finding X_c?

6. What is meant by leakage current in a capacitor? What causes it?

7. What is the total capacitance of three capacitors in series whose values are 10, 10, and 5 microfarads?

8. What is X_c for each capacitor in question 7, and the total capacitive reactance of 100 hertz? 10 kilohertz?

9. What is the total capacitance of three capacitors in parallel whose values are 10, 10, and 5 microfarads?

10. What is the total capacitive reactance for the three capacitors in question 9 at 100 hertz? 10 kilohertz? 1 megahertz?

Check-up: (2-4-4)

1. What is meant by the power factor of a circuit?

2. The apparent power in a circuit is 50 volt-amperes, and the true power is 40 watts. What is the power factor?

3. Why are paper, mica, and ceramic capacitors so called? Are these fixed or variable capacitors?

4. What is meant by the abbreviation WVDC that is found on a capacitor?

5. What is an electrolytic capacitor? Can it ever be used in an a-c circuit?

6. How are capacitors identified?

7. What is meant by rotor and stator plates? Do fixed capacitors have these?

8. Why are the polarities of electrolytic capacitors important? Can these always be used for d-c? For a-c?

9. The power factor of a circuit is 0.5. What is the phase angle between the voltage and current?

10. What is the power factor in a pure capacitive circuit? Resistive circuit?

MECHANICAL WORK ANALOGY OF POWER FACTOR

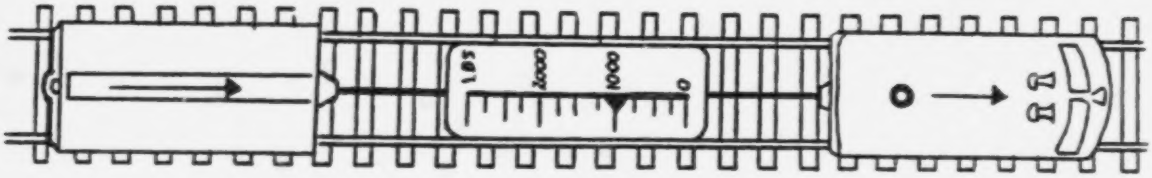


FIG. 1. FORCE APPLIED IN THE DIRECTION OF MOTION

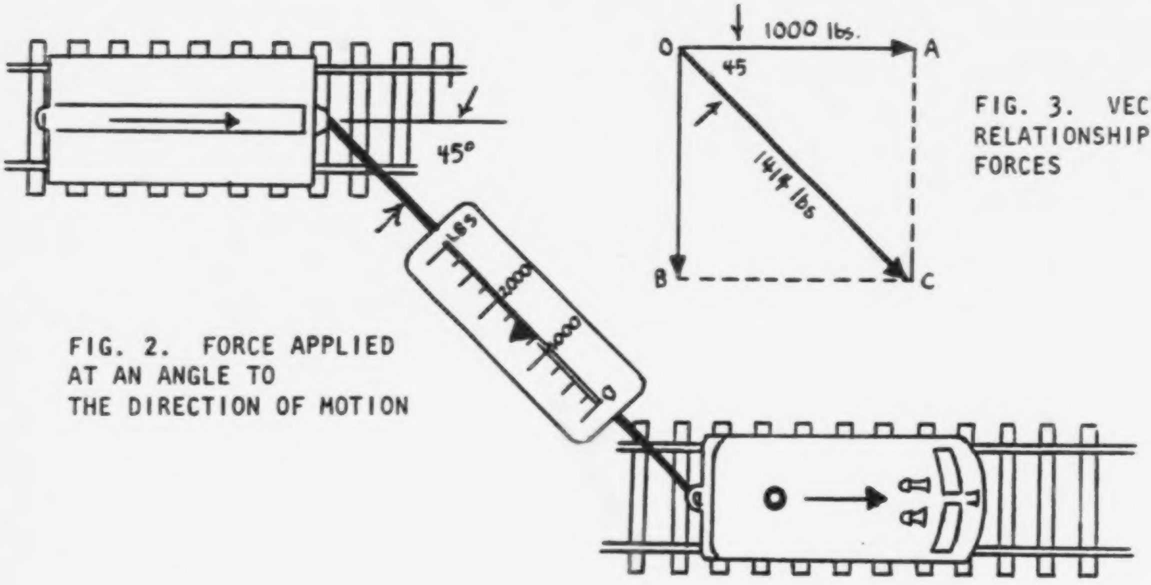


FIG. 3. VECTOR RELATIONSHIP OF FORCES

FIG. 2. FORCE APPLIED AT AN ANGLE TO THE DIRECTION OF MOTION

In a mechanical sense, power, or rate of doing work, makes use of a formula: hp = FV/550; where hp = horsepower, F = force applied, in the direction of motion, in pounds, and V = distance the force acts, in feet per second. Note that the force applied is the amount in the direction of the motion.

In figure 1, a car is being towed at the rate of 10 feet per second with the necessary force, as measured on the spring scale, being 1,000 pounds. The power is then (1,000 times 10) divided by 550 = 18.2 horsepower.

In figure 2, the towing cable makes an angle of 45 degrees with the direction of motion. The towing force in the direction of motion is still 1,000 pounds. The force as registered on the spring scale is 1,414 pounds. The apparent power then is (1,414 times 10) divided by 550 = 25.7 horsepower (apparent power).

When the force and the motion are not in the same direction, a correction factor must be applied to the apparent to determine the actual power being exerted. This correction factor is the cosine of the angle between the apparent and actual power. A similar angle, known as the "phase angle," exists in alternating current circuits between the volts (force) and the amperes (rate of motion) and the correction factor is known as "power factor."

Power in A-C Series Circuits

In a pure resistance load that is connected to an a-c power supply, the current is exactly in phase with the applied voltage and the true power for this single phase condition can be calculated using any of the following equations.

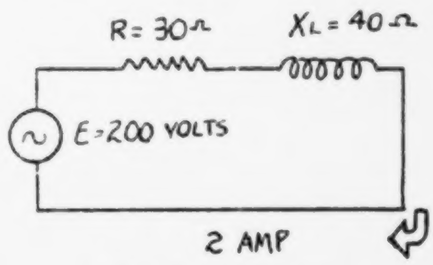
$$P = EI \qquad P = I^2R \qquad P = \frac{E^2}{R}$$

When a load is connected to an a-c power supply consisting of only inductive reactance, the current lags the applied voltage by 90 electrical degrees and no real power is consumed. The product of the applied voltage and the current is not watts, but volt-amps which, for this example, equal VAR's. Since there is no power (watts) consumed in forcing the reactive component of current through the circuit, this component is sometimes called the wattless component of the current. The fact that the circuit consumes no power does not mean that no energy is expended. We find it most convenient to think of coils requiring or consuming this type of energy and refer to it as reactive power. The reactive power unit is called the VAR (volt-amp-reactive) and is the product of the amperes, the volts, and the sine of the angle of lead or lag of the current.

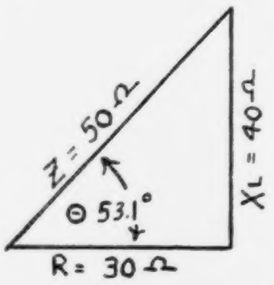
Another convenient concept is that VAR's are a form of magnetizing current. If you remember that the coil current lags its applied voltage by 90 degrees and the capacitor current leads its applied voltage by 90 degrees, we can think of coils as requiring or consuming magnetizing VAR's and capacitors may be considered as generating magnetizing VAR's. In the operation of an a-c power system both watts and magnetizing VAR's must be generated and the system will not perform without both. In generating plants and power stations this magnetizing energy is metered with a VAR meter while the real power is metered with a watt meter.

The Power Triangle

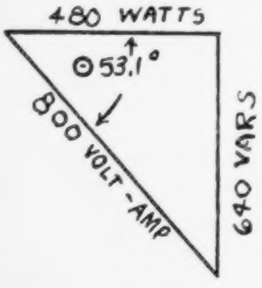
The power triangle is similar to the impedance triangle used in a-c series circuits. The base of the triangle represents the true power (a wattmeter measures this component). The hypotenuse represents the apparent power or volt-amps (this is the product of the amperes multiplied by the applied voltage). The altitude of the triangle is representative of the VAR's in the circuit (this is the product of the EI sine 0). The angle 0 represents the phase angle and tells the reader that the line current either leads or lags the line voltage.



SERIES CIRCUIT



Z TRIANGLE



POWER TRIANGLE

A-C SERIES CIRCUITS

You are to acquire from your study of the lessons that follow:

1. An understanding of how various combinations of resistance, inductance, and capacitance may be used to form a-c series circuits.

2. The ability to measure impedance values and phase angles graphically by the use of vectors and a protractor.

3. The ability to use and apply formulas for power and power factor in a-c series circuits.

4. A knowledge of how current, voltage, and resonance are affected in a-c series circuits containing resistance, inductance, and capacitance.

Directions:

1. Keep your notebook handy for terms, definitions, sketches, and formulas.

2. Read additional references and make it a point to observe a-c series circuits and their components.

3. Keep the study-help questions in mind while studying this assignment.

4. Answer all the check-up questions after carefully considering the aim of each question.

Study-help questions:

1. Show by diagram several ways in which combinations of resistance, inductance, and capacitance may be used to form a-c series circuits.

2. What does each of the following symbols represent: R, L, C, X_C, X_L, Z?

3. What is meant by circuit impedance?

4. What is a vector? How can vectors be of help to you in the electrical trade?

Lesson 2-4-5
THE SERIES RL CIRCUIT

Required reference:

Electricity One-Seven,

Check-up: (2-4-5)

1. In a vector diagram of the voltages in a series RL circuit, what circuit quantity is used as the reference vector? Why?

2. What is the 10-to-1 rule for R and X_L in a series RL circuit?

3. What is the resistance of a coil having a Q of 65, when the inductive reactance is 325 ohms?

4. What is the resistance in a series RL circuit when the impedance is 130 ohms and the inductive reactance is 50 ohms?

5. What is the phase angle for the circuit in question 4?

6. If an applied voltage of 100 volts causes 5 amperes of current in a series RL circuit, what is the circuit impedance?

7. The power dissipated in a circuit is 500 watts, the impedance is 10 ohms, and the phase angle is 60 degrees. What is the value of the current in the circuit?

8. What is the apparent power of a circuit which dissipates 500 watts, and has a power factor of 0.25?

9. Between what values (the maximum and minimum) can the power factor be found? Why?

10. What is the voltage across the coil in a series RL circuit when the applied voltage is 100 volts, and the voltage across the resistor is 80 volts?

100

Lesson 2-4-6
THE SERIES RC CIRCUIT

Required reference:

Electricity One-Seven,

Check-up: (2-4-6)

1. How do you show vectors representing resistance, capacitive reactance and impedance?

2. An inductive reactance and a capacitive reactance can have the same ohmic value, yet there is a difference between them. Explain, and construct vectors showing these differences between them.

3. A series circuit consists of a resistance of 150 ohms and a condenser of 10 microfarads. If a potential difference of 120 volts 60 hertz is applied across the circuit, find (a) the impedance of the circuit, (b) the current flowing through the circuit, (c) the potential difference across the resistance, and (d) the potential difference across the capacitor.

4. What is the resistance in a series RC circuit when the impedance is 130 ohms, and the capacitive reactance is 50 ohms?

5. What is the phase angle for the circuit of question 4?

6. The applied voltage across a series RC is 100 volts, and causes a current of 5 amperes to flow. What is the magnitude of the impedance of the circuit?

7. The power dissipated in a circuit is 500 watts, the impedance is 10 ohms, and the phase angle is 60 degrees. What is the value of the current in the circuit?

8. Two 10 microfarad capacitors are connected in series and this series combination of capacitors is connected in series with a 25-ohm noninductive resistor. If 240 volts were to be applied to this circuit, how many amperes would flow in the circuit?

9. A noninductive load with a resistance of 30 ohms is connected in series with a capacitor which has a capacitive reactance of 24 ohms. Determine: (a) the impedance of the circuit, (b) the current in amperes, and (c) the volts across the resistor.

10. In question 9 determine: (a) the power expended in the circuit, (b) the volt-amperes reactive component in VARS for the series circuit, and (c) the apparent power in volt-amperes.

LESSON 2-4-7
SERIES LC CIRCUITS

Required reference:

Electricity One-Seven,

Check-up: (2-4-7)

1. How do you show vectors representing current, capactive reactance and inductive reactance in a series circuit?

2. An inductive reactance of 600 ohms and a capacitive reactance of 200 ohms are combined in a circuit. (a) What is the impedance of the circuit? (b) If these values are reversed, that is, the inductive reactance equals 200 ohms and the capacitive reactance equals 600 ohms, then what is the impedance of the circuit?

3. Three henries pure inductive reactance and 0.4 microfarad pure capacitive reactance are connected in series, frequency at 60 hertz. (a) What is the impedance? (b) What is the phase angle? (c) What is the power factor? (d) Is the current leading or lagging the voltage?

4. Consider a series LC circuit with an applied voltage of 100 volts, a capacitor with a voltage of 140 volts across it, and an inductor with an inductive reactance of 20 ohms. (a) What current would flow in the circuit? (b) What is the impedance of the circuit? (c) What is the apparent power of the circuit?

5. In question 4: (a) What is the true power of the circuit? (b) What is the phase angle of the current in the circuit; is it leading or lagging?

6. In question 4, if the frequency of the applied voltage is doubled, what current would flow in the circuit? (Hint: The voltage across the capacitor would no longer be 140 volts.)

7. In question 6: (a) What would be the impedance of the circuit? (b) What current would flow in the circuit?

8. In question 4, if the frequency of the applied voltage were halved: (a) What would be the impedance of the circuit? (b) How much current would flow in the circuit? (c) What is the phase angle of the current in the circuit; is it leading or lagging?

9. In question 8: (a) What is the apparent power in the circuit? (b) What is the capacitive reactance?

10. In question 8: (a) What is the inductive reactance? (b) What is the reactive VARS of the circuit?

Lesson 2-4-8
SERIES LCR CIRCUITS

Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics, ...,

Check-up: (3-4-8)

1. The starting winding of a capacitor-start, induction-run motor consists of a resistance of 15 ohms and an inductive reactance of 20 ohms which are in series with a capacitor of 60 microfarads. The motor is connected to a 120-volt, 60-hertz power source. (a) What is the impedance of the series circuit? (b) How much current will flow in the circuit?

2. In question 1: (a) What is the power factor of the circuit? (b) How many watts of power will the start winding require?

3. A relay coil has a resistance of 100 ohms, an inductance of 0.2 henry and is to be connected in series with a 20 microfarad capacitor across a 120-volt, 60-hertz power source. (a) What is the total impedance of the circuit? (b) How many amperes will flow in this series circuit? (c) What is the impedance of the relay coil? (d) What is the power factor for this series circuit? Does the current lead or lag the voltage?

4. A series LCR circuit has an applied voltage of 200 volts, an impedance of 100 ohms, an inductive reactance of 50 ohms, and a capacitive reactance of 130 ohms. (a) What is the value of the resistance? (b) What is the current in the circuit? (c) What is the phase angle of the circuit? Does the current lead or lag the applied voltage? (d) What is the true power? (e) What is the apparent power?

5. A series LCR circuit consists of 8 ohms resistance, 18-ohms inductive reactance and 12-ohms capacitive reactance. (a) What is the impedance of the circuit? (b) What is the true power? (c) What is the reactive power?

6. A coil containing 100-ohms resistance and 0.50-henry inductance is placed in series with 40 ohms of capacitive reactance and a 30-ohm resistance across a 60-hertz, 480-volt a-c circuit. How much current will flow in the circuit?

7. What is the voltage across the coil in question 6?

8. How many watts of power is being extended in the coil in question 6?

9. How much power is being expended in the resistor in question 6?

10. (a) Can the voltage across the inductor or the capacitor in series LCR circuit ever be greater than the applied voltage? (b) Can the voltage across the resistor ever be greater than the applied voltage?

Lesson 2-4-9
SERIES RESONANCE

Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Check-up: (2-4-9)

1. What does the impedance of a series circuit equal when the inductive reactance equals the capacitive reactance? What is this condition called?

2. A series circuit has a resistance of 60 ohms, an inductance of 63.66 milihenry and a capacitance of 110 microfarads. Determine the frequency at which this circuit will resonate.

3. What is the value in ohms of the impedance of the circuit in question 1 at resonance?

4. If 120 volt, 60 hertz were applied to the series circuit in question 1, what voltage would exist across the inductor?

5. In question 4, what current would flow at resonant frequency?

6. What is the power factor of a series circuit when resonance is reached?

7. How much capacity is required to obtain resonance at 1,000 kilohertz with an inductance of 50 microhenries?

8. What is the value of the current in a series circuit at resonance; is it minimum or maximum?

9. At resonance, is series LCR circuit inductive?

10. Most radio receivers employ one or more tuned circuits. Tuning is selecting a signal at one frequency and rejecting signals at all other frequencies. What is another use of series resonant circuits?

Note: The new term now in use for micromicrofarads is the picofarad. Remember, the microunit is one millionth of a unit. The micromicro unit is one millionth of one millionth of a unit. That is, 1 farad is equivalent to 1,000,000,000,000 picofarads. The pico unit is seldom used for anything other than farads. It is represented by p. Many texts still use the microunit abbreviated MM (Greek letter Mu). Thus 1 u = 1 pf.

Mathematically: $1 = 1 \text{ times } 10^{-12}$

A-C PARALLEL

AND SERIES - PARALLEL CIRCUITS

Careful study of the lessons which follow will give you:

1. An understanding of the various a-c parallel circuit combinations and how voltages, currents, impedance, and power factors are determined in circuits containing resistance, inductance, and capacitance.

2. An understanding of a-c series-parallel circuits and the ability to apply "vectors" and Ohm's Law in finding total current, branch currents, and impedance in these complex circuits.

3. The ability to use new terms when reading, studying, writing, or otherwise expressing ideas in your trade.

Directions:

1. Study the references thoroughly and make certain that you understand each theory, principle, or formula before advancing to the next topic. Familiarize yourself with all new words, terms, and definitions. Keep your notebook up to date.

2. Write out and hand in to your instructor the answers to all the check-up questions after carefully considering the aim of the questions. When words alone fail to convey your meanings, make sketches, drawings, or diagrams.

3. Read the additional references that are assigned by your instructor.

Study-help questions:

1. When working with a-c parallel circuits, why is it not possible to obtain the total current 1_T by adding the various branch circuits directly?

2. With d-c parallel circuits, the voltage across each of the parallel branches is the same. Does this hold true in a-c parallel circuits?

3. Does the voltage value vary with the number of parallel branches of an a-c parallel circuit?

4. What is meant by "internal" and "external" circuits when working with a-c parallel circuits?

5. How would you find impedance in an a-c parallel circuit by using Ohm's Law?

6. Can you find parallel circuit impedance and power factor by the use of vectors?

7. What is meant by a "parallel resonant" circuit? What formulas can be used for computing the circulating current?

8. When working with "complex circuits," is it necessary to consider the parts of the circuit separately?

Lesson 2-4-10
CHARACTERISTICS OF A-C PARALLEL CIRCUITS

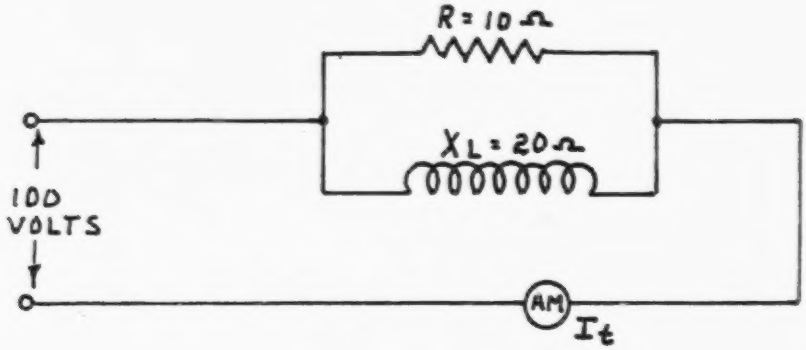
Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Check-up: (2-4-10)

1.



In the above circuit:

(a) What does I equal?

(b) What does I_R equal?

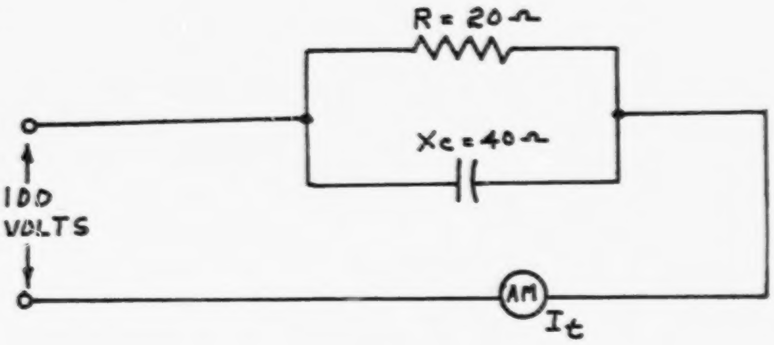
(c) What does I_L equal?

(d) What is the impedance of the circuit?

(e) What is the power?

(f) What is the power factor of the circuit?

2.



In the above circuit:

(a) What does 1   equal?

(b) What does 1_C equal?

(c) What is the impedance of the circuit?

(d) What is the apparent power? The true power of the circuit?

(e) What is the power factor of the circuit?

3. What determines the flow of current through each individual branch of an alternating-current parallel circuit?

4. Why cannot the branch currents be added directly to obtain the total current in an a-c parallel circuit?

5. Is direct addition permissible with the various branch currents in a direct-current parallel circuit?

6. In a parallel a-c circuit consisting of several branches, what may be said of individual branch circuit voltages?

7. What is meant by "equivalent series circuit?"

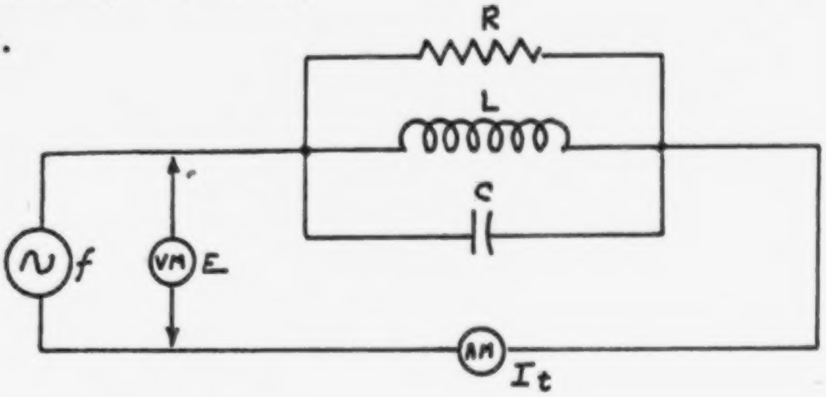
8. If a 20-ohm resistor and a 15-ohm capacitive reactance are connected in parallel, what would the equivalent series circuit equal?

9. How may the power factor of a parallel a-c circuit be determined?

10. In vector diagrams for series RL circuits, what circuit quantity is used as the reference vector? Why? What is the reference vector for parallel RL circuits? Why?

Check-up: (2-4-11)

1.



R
L
C
f
VM
E
AM
It

In the above circuit, if R = 60 ohms, L = 0.064 henry, C = 112.5 microfarads, E = 120 volts, and the frequency = 60 cps:

(a) What does I_R equal?

(b) What does I_L equal?

(c) What does I_C equal?

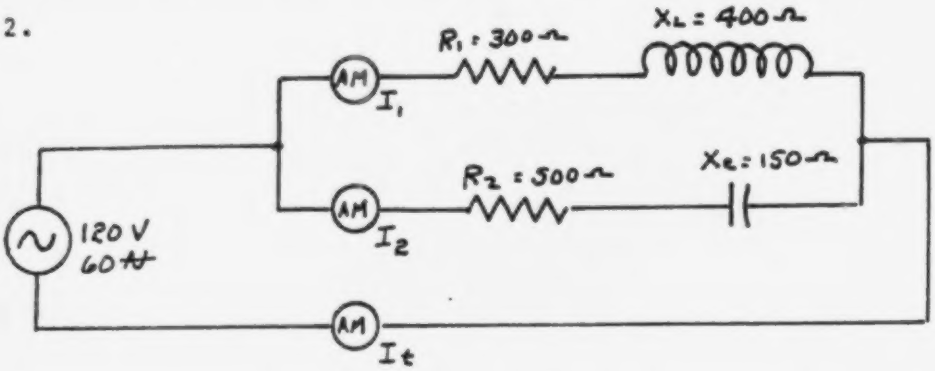
(d) What does I_t equal?

(e) What does Z equal?

(f) What does pf equal?

(g) What amount of power is expended in the circuit?

2.



R₁ = 300 Ω
X_L = 400 Ω
AM
I₁
R₂ = 500 Ω
X_C = 150 Ω
AM
I₂
120 V
60 ~
AM
It

(a) What value of current is I_t ?

(b) What value of current is I_1?

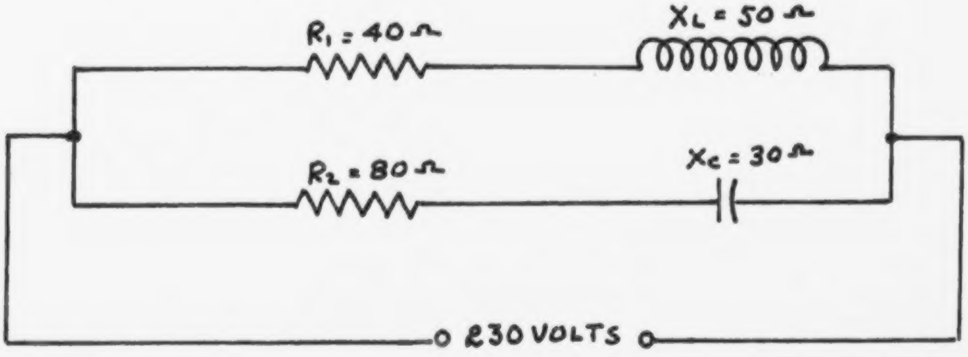
(c) What value of current is I_2?

(d) What is the impedance of each branch?

(e) What amount of power is expended in the circuit?

(f) What is the power factor?

3. If 230 volts are impressed across the circuit below:



(a) What is the impedance of branch 1?

(b) What is the impedance of branch 2?

(c) What is the phase angle of branch 1?

(d) What is the phase angle of branch 2?

(e) How much current will flow in branch 1?

(f) How much current will flow in branch 2?

(g) What is the value of the total current?

(h) What is the total impedance of the circuit?

(i) What is the power factor of the circuit?

(j) What amount of power is expended in the circuit when it is operating at 230 volts?

Lesson 2-4-12
RESONANCE IN A-C CIRCUITS

Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Check-up: (2-4-12)

1. What happens to the external-circuit current when the resistance is zero, and the inductive reactance and the capacitive reactance are equal, if connected in parallel?
2. Assuming that we have only inductance, L, and capacitance, C, in an alternating-current series circuit, what is the impedance at resonant frequency? What is the impedance for a resonant parallel circuit?
3. What is meant by "internal circuit;" external circuit?"
4. What is meant by "circulating current?"
5. Why is parallel resonance sometimes called "anti-resonance?"
6. Is there any change in the voltage when resonance is reached in a parallel alternating-current circuit?
7. What does the line current equal in a parallel resonant circuit?
8. What prevents the total current from becoming zero when resonance is reached in alternating-current parallel circuit?
9. Explain the difference between the voltage at series and at parallel resonance in an a-c circuit; the current; the impedance.
10. What is the resonant frequency of a parallel circuit consisting of a capacitance of 400 micromicrofarads in one branch and an inductance of 240 microhenries in the other branch?

TRANSFORMERS

The following lessons are intended to help you acquire:

1. A general knowledge of the classifications and types of transformers and an understanding of their basic differences and how they function.

2. An appreciation of the importance of transformers and how they are used in your trade.

3. An understanding of terms common to transformers and transformer operation.

Directions:

1. Study catalogs of transformers and note the different types, sizes, and specifications.

2. Familiarize yourself with all new words, terms, and definitions. Enter them into your notebook.

3. Write out the answers to all of the check-up questions and turn them into your instructor.

4. Study additional information from the various reference materials recommended by your instructor.

Study-help questions:

1. What is the basic function of a transformer?

2. What is the difference between a step-up and a step-down transformer?

3. What is meant by "emf of mutual induction" with regard to transformer action?

4. If a transformer does not generate electric power, what actually happens?

Lesson 2-4-13

BASIC PRINCIPLES OF TRANSFORMER OPERATION

Required reference:

Electricity One-Seven,

Additional reference:

American Electricians' Handbook,

Additional information:

Transformers are generally considered the most important single type of equipment in the entire process of distribution of electrical power. If electrical energy is to be transmitted with economy over any considerable distance, the transmission voltage must be high, so the line losses will be a minimum. You have already learned from Ohm's Law that the voltage drop in a given line is a function of the current flow multiplied by the resistance, or by the impedance in an a-c circuit. If we assume that a line of several miles in length has an impedance of 5 ohms and we attempt to transmit power over this line, the voltage at the generated end and the receiving end would, for all practical results, be the same as long as there is no current flow. If, however, 2 amperes were made to flow over this circuit, there would be a voltage drop equal to ZI or, 5 x 2 or 10 volts, in the line. The power loss in the line would be P = EI or 10 volts times 2 amps = 20 watts. If the current were found to be more in the order of 400 amps, however, the voltage drop in the line would be 5 ohms times 400 amps = 2,000-volt drop, and a loss equal to 2,000 volts times 400 amps or 800 kilowatts is a considerable loss. You can see that transmitting a large amount of current is impractical, also, in order to carry large currents the wire size would have to be unnecessarily large.

Actually, in addition to amperes we transmit electrical energy, or power, measured in watts. If a customer uses 50 amperes at a voltage of 120, 6,000 watts will be used. Buy stepping up the voltage, the amount of current can be reduced to a point where there will be much less voltage drop and loss in the line. Six thousand volts times 1 ampere also equals 6,000 watts. Transmission voltages in common use today run many times higher than this--500 kv, 230 kv, 115 kv and 69 kv being some of the most common used.

It is not feasible to generate electrical energy at the high voltages that must be used for transmitting large amounts of energy over great distances. Therefore, where the energy is generated at a low voltage, a step-up transformer is used to raise the generator voltage to one suitable for transmission, and then a step-down transformer is used to decrease the voltage for utilization. This is usually done in several steps.

At distribution substations, voltage is usually reduced to a level of 13.8 kv, 13.5 kv, 11 kv, 7,200 or 4,150 volts, and carried on neighborhood lines. From this, still further reductions are made by use of the smaller pole-type transformers, to the 120/240 volts used by the average business or residential customer.

Transformers, it is evident, play a vital part in the electrical industry. The transformer is a device operated on the principle of mutual induction. It is remarkably simple in principle and in construction because it involves no moving parts. Some of the reactions that occur within a transformer, however, are extremely complicated and tedious to explain.

The section on transformers in Volume 3 of Electricity One-Seven discusses mainly small dry-type transformers, but regardless of the size of a transformer, whether a 50-volt ampere unit or a 15-mva unit, the principles are the same. It must have a laminated iron core and a set of windings for the particular voltages which are to be used.

Check-up: (2-4-13)

1. What function of electricity makes the use of transformers possible?

2. What is meant by the "magnetic circuit" of a transformer?

3. What is the phase relationship between the primary and secondary voltages of a transformer?

4. Is the magnetic circuit always through the core?

5. What is the turns ratio of a transformer?

6. What is meant by the "ratio" of a transformer?

7. When the voltage of a circuit is raised to a higher value by use of a transformer, what effect does this have on the current of the circuit?

8. What is meant by "ampere-turns?"

9. In an ideal transformer, what is the relationship between the power primary and the power developed by the secondary?

10. What constitutes the losses incurred in a transformer?

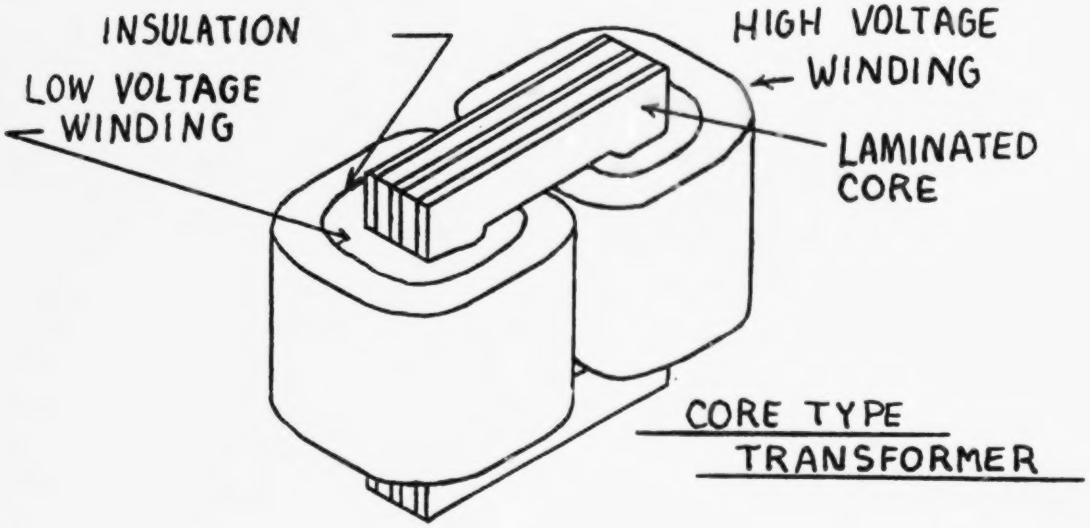
11. What is hysteresis loss?

12. What are eddy currents and how are they held to minimum in transformers?

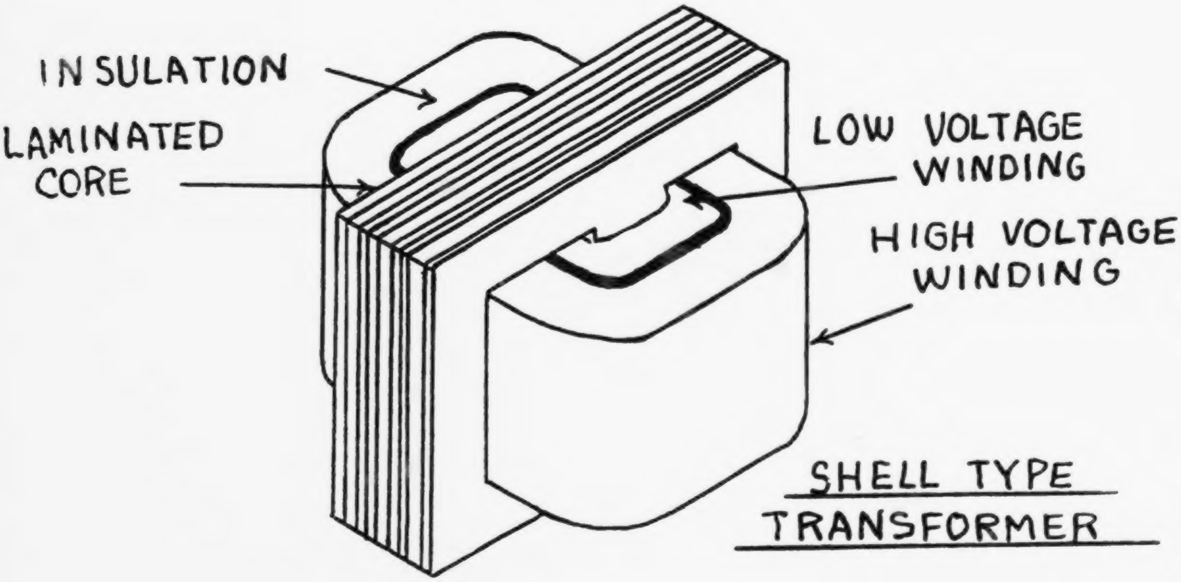
13. What is meant by transformer efficiency?

14. What is meant by saturated core?

15. What is an autotransformer?


INSULATION
LOW VOLTAGE WINDING
HIGH VOLTAGE WINDING
LAMINATED CORE
CORE TYPE TRANSFORMER

Note: In the core type transformer the coils surround the core. This construction is used for moderate voltage, moderate size transformers.


INSULATION
LAMINATED CORE
LOW VOLTAGE WINDING
HIGH VOLTAGE WINDING
SHELL TYPE TRANSFORMER

You will notice that in the shell-type transformer the core encloses the coil assembly. The shell-form construction has some inherent advantages in thermal characteristics and electrical and mechanical strength; it is preferred for most large, high-voltage transformer applications.

Lesson 2-4-14
CLASSIFICATION OF TRANSFORMERS AND TYPES OF CONSTRUCTION

Required reference:

American Electricians' Handbook,

Additional information:

Transformers, in general, are classified according to how they are used. Power transformers are large transformers used at generating stations to step up the voltage, and at substations to step down the voltage, for supplying distribution or transmission systems. Power transformers may also be used for tying together two power systems.

Distribution transformers are primarily transformers used to step down from a distribution voltage to a voltage suitable for industrial plant, residential, or commercial use, usually 480, 240 and 120 volts. Such transformers are rated from 1.5 to 500 kva in size. A 500 kva transformer is the highest rated transformer to be classed as a distribution transformer.

Instrument transformers are small transformers of about 200 or 500 va in rating and are generally of two types; the potential transformer and the current transformer. Current transformers are connected in series with the line in order to permit the use of low-voltage and low-current instruments and relays. Other types that could be listed are: sign lighting, door bell, and constant current or street-lighting transformers.

Check-up: (2-4-14) Instructor's Note: Apprentice metermen may omit this check-up.

1. In power transformers, core type, what winding is usually found next to the core leg?

2. Why is it necessary in power transformers to brace the windings well, especially near the ends of the windings?

3. How are the primary and secondary windings placed with relation to each other on the core?

4. How are the primary and secondary windings insulated from one another?

5. What materials are used for insulation?

6. How does oil rank as an insulator and what qualities has it that make possible its wide use in transformers?

7. What kind of oil is used in transformers?

8. What dielectric test should a good transformer oil stand?

9. Why must the insulation be made extra heavy on the end turns of high voltage transformers?

10. What is an inertaire transformer?

11. What provisions are provided for the expansion of oil in transformers?

12. Why is nitrogen used in transformers?

13. What does 55 degrees centigrade temperature rise mean?

14. What is a CSP distribution transformer?

15. Calculate high-side and low-side amps of a single-phase transformer rated at 2,300/230/115 volts, 25 kva.

16. Same question is used in check-up (111-6-D). If a transformer is rated at 150 kva, what would be its kw rating at 80 percent power factor?

17. Can a transformer be used at a lower than rated voltage?

18. Why are transformers rated in kva and not in kw?

19. In some locations where oil-cooled transformers are considered a fire hazard, what other methods may be used to cool transformers?

20. The current input to the primary winding, with no load connected to the secondary winding, is usually from 2 to 5 percent of full-load current. This is normally called exciting current, or charging current. What should be the charging current in a 2,500 kva, a single-phase transformer rated at 11,000 to 2,400 volts?

Additional information:

Transformer Impedance. The impedance of a transformer is the combined effect of resistance and reactance drops usually given in percent impedance. In an actual transformer, the percent impedance may be easily obtained by measuring the primary voltage required to force full-load current through the secondary short circuited and expressing the result as a percentage of the rated primary voltage, usually between 3 and 6 percent.

For example, if a 10 kva transformer rated 2,400/240 volts were to be tested, we should divide 10,000 va (transformer rating) by 240 volts to find 41.6 amps rated current in the secondary. Then with the secondary short circuited (X1 to X2), we find it took 120 volts applied to the primary (H1 to H2) to cause 41.6 amps (rated current) to circulate in the secondary; this would be the impedance voltage. The percent impedance voltage is the ratio of impedance volts to the rated terminal volts, or 120 volts/2,400 volts = 5 percent.

Polarity Markings. The American Standards Association (ASA) has standardized the method of marking transformer terminals to indicate the polarity of the windings. The leads H1, H2, X1, X2, are so marked that when the instantaneous voltage is from H1 to H2, it is also from X1 to X2. In a transformer where H1 and X1 are adjacent, as in Figure 6-a, the transformer is said to be "subtractive polarity." In a transformer where H1 and X1 are placed diagonally, as in Figure 6-b, the transformer is said to be "additive polarity." The standard says the H1 lead is brought out on the right-hand side of the case, facing the high-voltage side of the transformer case.

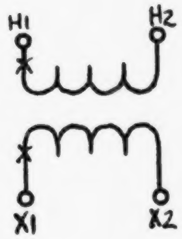


Figure 6-a SUBTRACTIVE

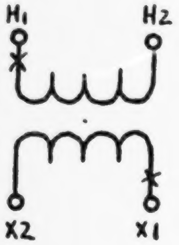


Figure 6-b ADDITIVE

If the leads are not marked, or if it is desirable to check the polarity of a transformer, a test lead may be installed to connect the high-voltage lead on the left to the low-voltage lead on the left and a relatively low-test voltage applied to the high-voltage leads, as shown in Figure 6-c. The transformer is additive polarity if VM 1 + VM 2 = VM 3, and the transformer is subtractive polarity if VM 3 = VM 1 - VM 2.

Polarity may also be determined by flashing the high-voltage winding with a battery. With direct current passing through the high-voltage winding, with positive of the battery to H1 and negative to H2, and a d-c voltmeter connected to the secondary winding with positive lead to X1 and the negative lead to X2, the pointer on the voltmeter will make a positive, or up-scale, deflection when the battery is connected and it will swing in a negative direction, or down scale, when the battery is disconnected. The polarity of direction or down scale when the battery is disconnected. The polarity of both potential and current transformers may be checked in this manner.

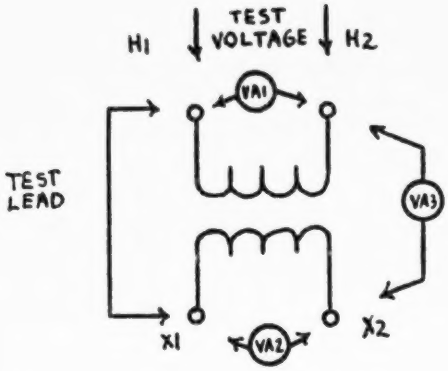
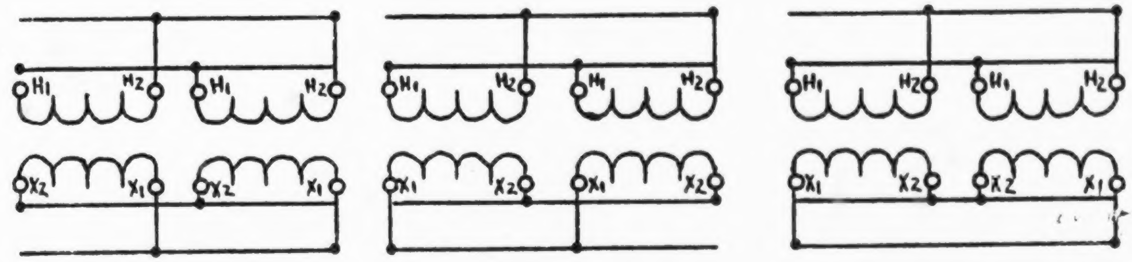


Figure 6-c TEST FOR POLARITY

All transformer testing involves the hazard of high voltage. Because of this, low-test voltage should always be used and care should be taken to see that this voltage is not inadvertantly transformed to a high potential. No one should be allowed to make tests on transformers until the person has been instructed in the hazards involved and the proper safety precautions.

The ASA and National Electrical Manufacturers Association (NEMA) transformer standards says that all single-phase transformers up to 200 kv and having a voltage rating not in excess of 9,000 volts shall be made of additive polarity. Subtractive polarity shall be standard for all single-phase transformers in sizes of 200 kva and above, having high-voltage rating above 9,000 volts.

Single-phase Paralleling. If greater capacity than one transformer can handle is required, two transformers of the same, or different, kva ratings may be connected in parallel. Single-phase transformers of either additive or subtractive polarity may be paralleled if connected as shown in Figure 6-d and if the following conditions are met: (1) voltage ratings are identical; (2) tap-settings are identical; (3) impedance of one is between 92.5 percent and 107.5 percent of the other; and (4) frequency ratings are identical.



PARALLELING TWO TRANSFORMERS WITH ADDITIVE POLARITY

PARALLELING TWO TRANSFORMERS WITH SUBTRACTIVE POLARITY

PARALLELING TWO TRANSFORMERS, ONE SUBTRACTIVE POLARITY

Fig. 6-d

Transformers will not operate satisfactorily in parallel unless their turns ratios are very close to the same. A difference in turns ratios will cause a circulating current to flow, even at no load. The impedance has an effect on parallel operation. If the impedance percents are the same, they will divide the load properly.

Transformer Connections. Practically all residential consumers and many commercial installations require single-phase, three-wire service. One transformer only need be used. Its secondary windings should be connected in series and a tap made between the two windings of the distribution transformer to which the neutral is connected. This provides 240 volts between the two outside wires for heating or appliances, and two circuits of 120 volts for lighting and plug receptacles. The current in the neutral of a single-phase, three-wire noninductive circuit is the difference between the currents in the two line wires. If the currents in the two windings are balanced, the current in the neutral wire is zero. The neutral should always be grounded for safety's sake.

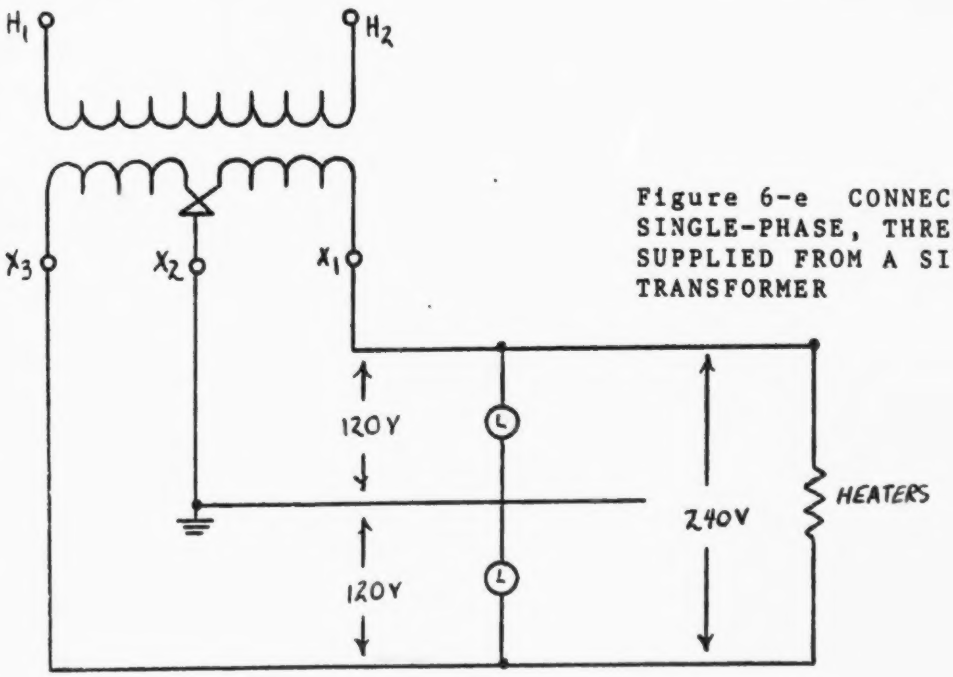


Figure 6-e CONNECTIONS FOR A SINGLE-PHASE, THREE-WIRE SYSTEM SUPPLIED FROM A SINGLE-PHASE TRANSFORMER

Sometimes when the load requires only a 120-volt supply, the connections on the secondary of a distribution transformer may be changed inside the tank from the normal series connection to a parallel connection, as shown in Figure 6-f, in order to take advantage of the full capacity of the unit.

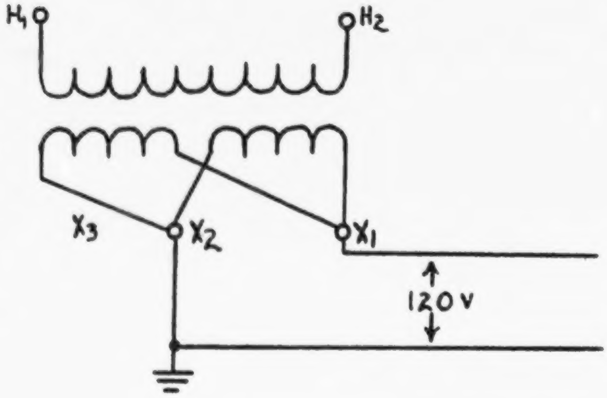


Figure 6-f

Tap Changers. Many transformers are provided with taps to permit changes in the voltage ratio. The simplest method is to have the tap points of the high-voltage winding brought out to a small terminal located inside the transformer. By changing the tap connections, the number of turns on the primary winding are changed. These taps are usually located in the center of the winding or near the neutral end away from line surges. The use of a terminal board makes it necessary to lower the oil level, open the manhole, and use tools to make the change. The tap changer is, therefore, commonly used on practically all transformers of any size. The ordinary tap changer is operated only with the transformer de-energized and is really a switch which, when moved to different positions, cuts out sections of windings to decrease the turns ratio between the primary and secondary windings and thereby increases the secondary voltage.

Sometimes power transformers are provided with equipment for changing their voltage ratio under load by moving the tap changer in a compartment entirely separate from the transformer tank, immersed in oil, and usually driven by a small motor. Transformers with "load-ratio control," as it is commonly called, are used for regulating voltage on distribution systems.

Three-phase Connections. Nearly all electrical power today is generated by three-phase generators, and transmitted and distributed over three-phase circuits. The generator generates three voltages of the same magnitude and frequency, 120 degrees apart. Power systems are either delta or wye, the delta having three power lines, and the wye having three power lines and a neutral. Transformers are used on these two types of systems to step the voltage up and down as required and also use two basic types of connections, either delta or wye.

To understand better the many problems associated with transformer connections, you should have some knowledge of vector diagrams, or "phasors," as they are sometimes called, and voltage diagrams. The usual method of representing quatities in a vector diagram utilizes the root-mean-square or effective values of current or voltage as the magnitude of the vector. Since vectors represent quantities which alternate at a frequency of 60 cycles per second, the vector can be assumed to rotate 360 degrees in one complete cycle, and counterclockwise rotation has been universally accepted as standard. Figure 6-g shows three voltage vectors, 120 degrees apart. The position of these vectors is relative and of an arbitrary location. Once the reference is chosen, the position of the voltage vectors with respect to each other becomes fixed. Voltage transformation on three-phase systems may be accomplished by using three single-phase transformers whose core structure consists of three legs with the low and high voltage windings for each phase wound on one of the three legs. The diagrams of three-phase transformers normally employ a system of numbering in place of arrows.

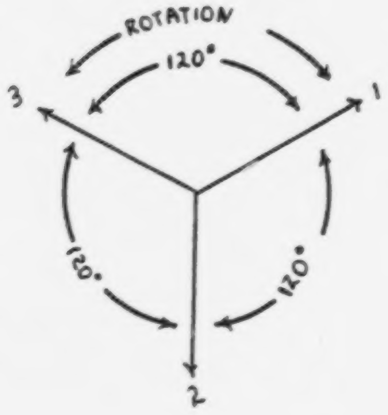
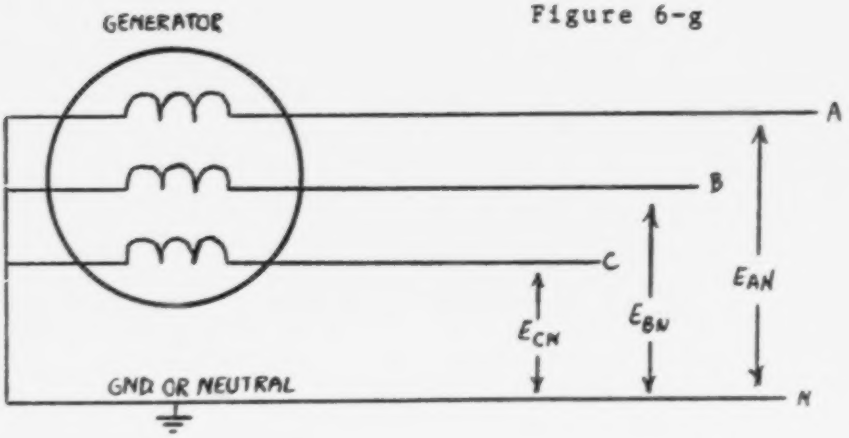
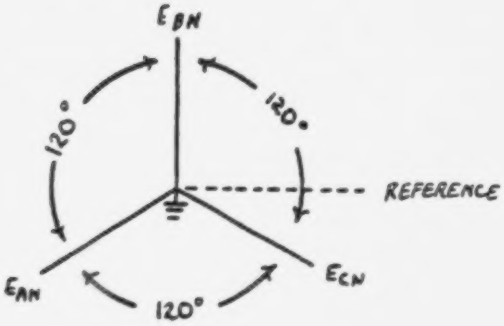
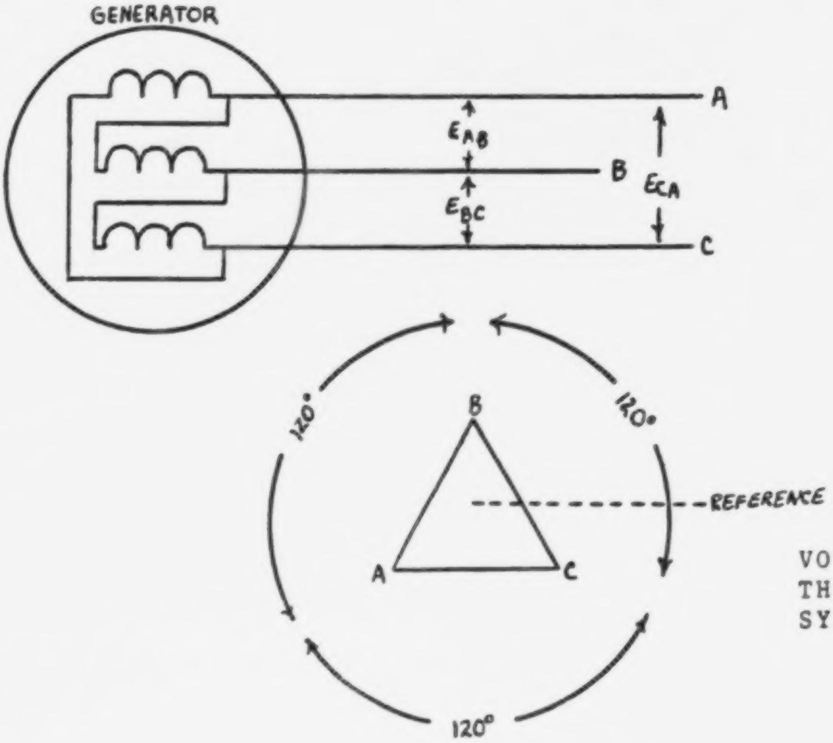


Figure 6-g



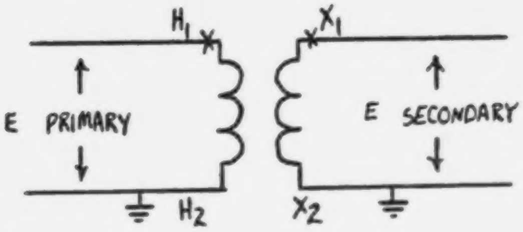

E_BN
120°
120°
REFERENCE
E_AN
120°
E_CN

VOLTAGES IN A
THREE-PHASE WYE
SYSTEM

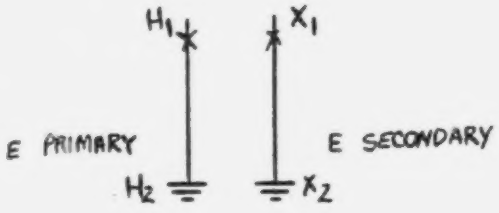

GENERATOR
A
E_AB
B
E_CA
E_BC
C
120°
120°
B
REFERENCE
A
C
120°

VOLTAGES IN A
THREE-PHASE DELTA
SYSTEM

Three-Phase Voltage Diagrams. You will remember that the voltage drop from polarity to nonpolarity on the primary side is substantially in phase with the voltage drop from polarity to nonpolarity on the secondary side.

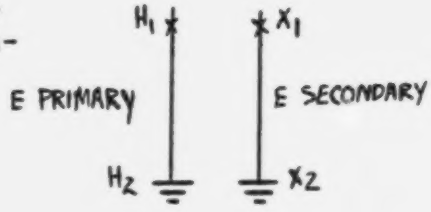

H1
X1
E PRIMARY
E SECONDARY
H2
X2

SUBTRACTIVE TRANSFORMER

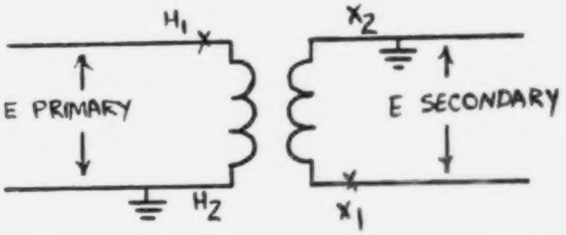

H1
X1
E PRIMARY
E SECONDARY
H2
X2

VOLTAGE DIAGRAM FOR A SINGLE SUBTRACTIVE TRANSFORMER

Therefore, the primary and secondary vectors, or phasors, must be substantially in phase also.

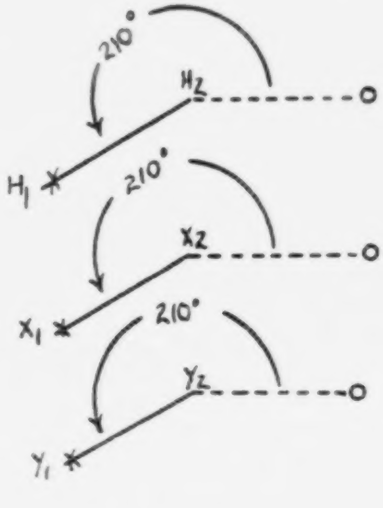

H1
X1
E PRIMARY
E SECONDARY
H2
X2

VOLTAGE DIAGRAM FOR A SINGLE ADDITIVE TRANSFORMER


H1
X2
E PRIMARY
E SECONDARY
H2
X1

ADDITIVE TRANSFORMER

You will note that in the voltage diagrams H1 and H2 are always shown in phase with X1 and X2. Whether the transformers are wound additive or subtractive, the polarity for the voltage diagram must be shown in PHASE.

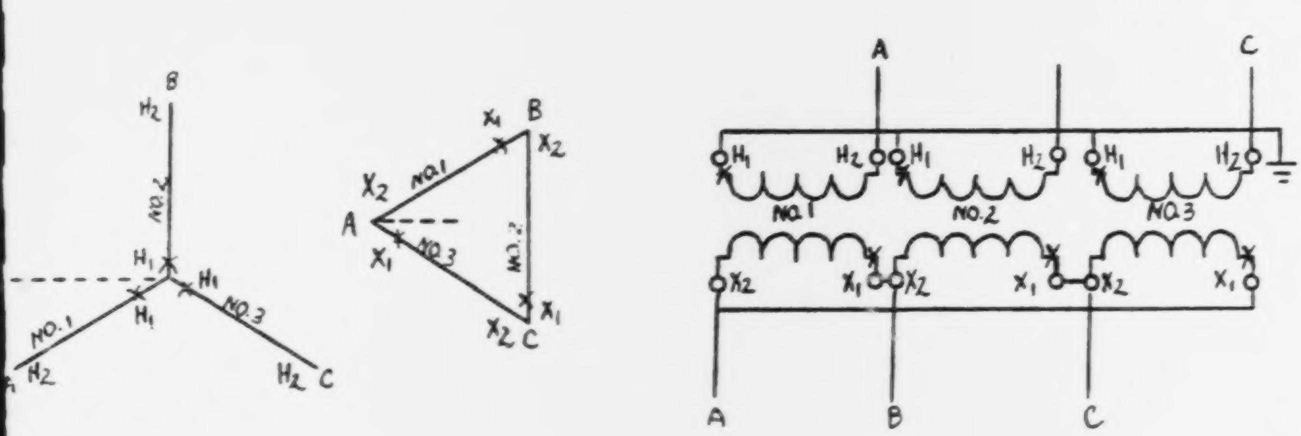

210°
H2
H1
210°
X2
X1
210°
Y2
Y1

This is the principle that is applied in constructing the transformer connections diagrams for three-phase operation. It also follows that if H1 H2 (primary winding) be placed at a position 210 degrees from zero, then X1 X2 (secondary windings) must be substantially in phase with it, or 210 degrees. Often transformers have three windings (tertiary) and because all windings are on the same core, the voltages are all substatially in phase.

If you can assume yourself standing at some reference point watching the vectors rotate in a counterclockwise manner, you would note that the order of rotation would be A, then B, then C, and etc. This A, B, C rotation is referred to as positive rotation or positive sequence. A rotation of A, C, B would be reverse or negative sequence. The normally-balanced system is said to produce these three vectors equal in magnitude, 120 degrees out of phase and rotating in a direction so they reach their positive maximum values in a sequence of A, B, C. You will notice in Figure 6-i, "Y-Y Connection," that the primary and secondary vectors are all in the same rotation and in the same phase. The vectors in Figure 6-j, "Y-Y Connection," however, show the A -secondary would lag behind the primary A vector by 180 electrical degrees, as you observe from your reference point. Note also that the phase sequence is still A, B, C, or positive. The AIEE standards provide that the leads shall be marked in such a way that phase rotation of high and low voltages H1, H2, X1, X2 shall be the same. That is, if a three-phase motor were transferred from the high-voltage circuit to the low-voltage circuit, its direction of rotation would be the same.

Transformers on three-phase systems are connected in any one of four standard ways. The wye-wye connection just described, the wye-delta connection, the delta-wye connection, and the delta-delta connection.

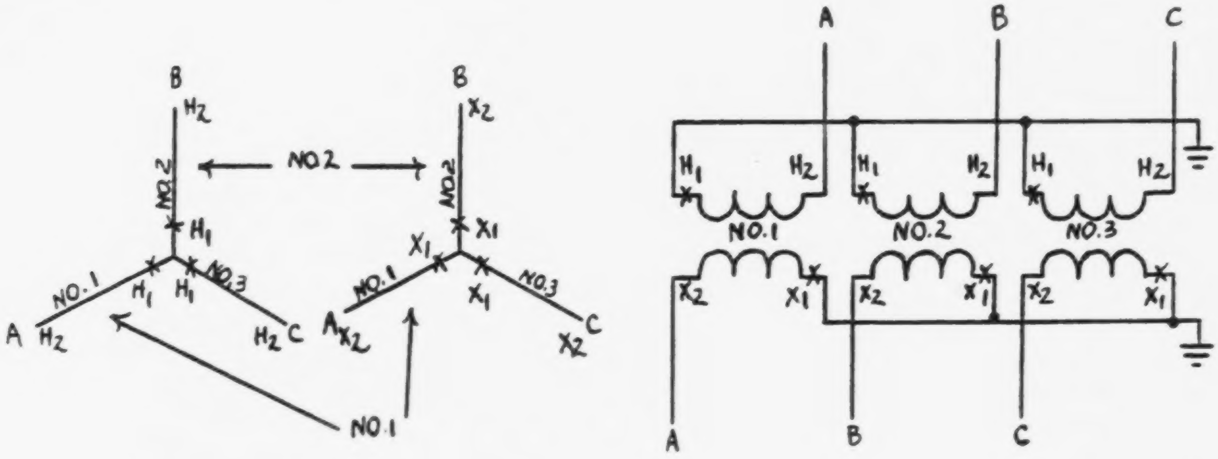
Wye-Delta Connection. The wye-delta connection is used primarily on a wye power system. The high side is connected wye and the lowside delta. The low side is usually used to supply loads requiring three-phase only. A wye connection on the low side can be used to supply loads requiring both single-phase and three-phase.



WYE-DELTA CONNECTION WITH 30° DISPLACEMENT

Figure 6-k

The voltage diagram (sometimes referred to as the "vector diagram") for a 3 0 transformer connection using three single-phase transformers is shown in Figure 6-i with the transformers being labeled 1, 2, and 3, for clarity.


B
H2
NO.2
H1
NO.1
H1
H1
NO.3
A H2
H2 C
B
X2
NO.2
X1
X1
NO.1
X1
NO.3
A X2
X2 C
NO.1
A
B
C
H1
H2
NO.1
NO.2
NO.3
X2
X1
A
B
C

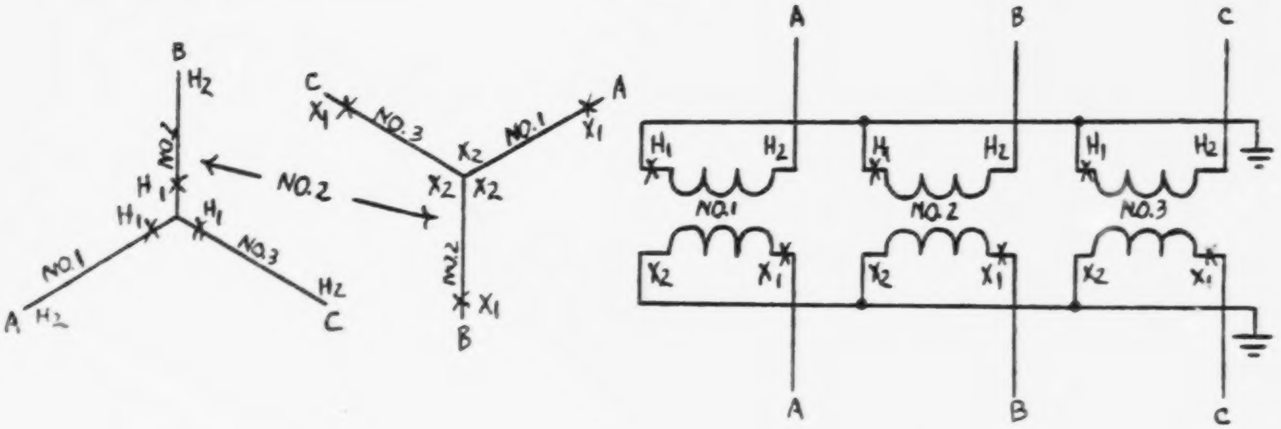
VOLTAGE DIAGRAM

CONNECTION DIAGRAM

Y-Y CONNECTION WITH 0° PHASE DISPLACEMENT

Figure 6-i

The same transformers could be connected as shown in Figure 6-j.


B
H2
NO.2
H1
H1
H1
NO.1
NO.3
A H2
H2
C
NO.2
C
X1
NO.3
X2
NO.1
A
X1
X2
X2
NO.2
X1
B
A
B
C
H1
H2
NO.1
NO.2
NO.3
X2
X1
A
B
C

VOLTAGE DIAGRAM

CONNECTION DIAGRAM

Y-Y CONNECTION WITH 180° PHASE DISPLACEMENT

Figure 6-j

When three transformers are operated with their high-voltage windings in wye, the incoming line voltage is the square root of 3 or 1.732 x the transformer winding voltage. Many three-phase transformer banks used to step-down three-phase voltages of 60 kv or higher are connected in wye-delta. It is also a convenient way of boosting the transmission voltage without purchasing additional transformers. To obtain the total kva capacity of the transformer bank, the kva ratings of the individual transformers are added.

Angular displacement between the high-voltage and low-voltage windings is the angle between the lines passing from the neutral point as reference. You will note that in Figure 6-k the A secondary is lagging the A primary by 30 degrees. Angular displacement becomes important when two or more three-phase banks are interconnected into the same secondary system or when interconnections are made between two power systems.

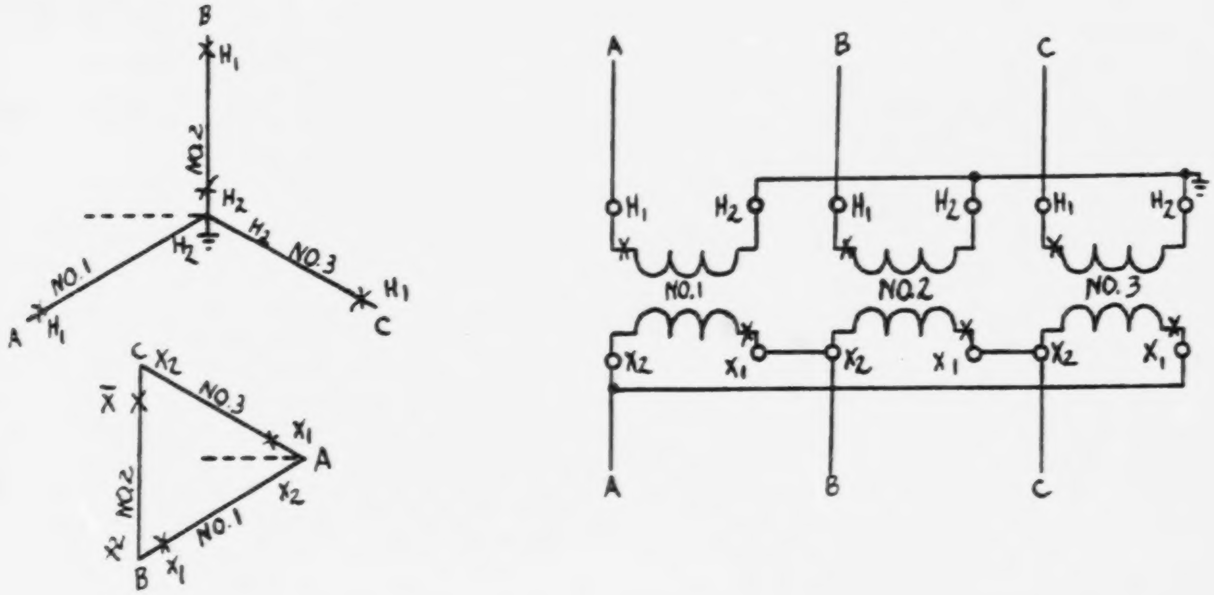


Figure 6-1 WYE-DELTA ALTERNATIVE CONNECTION WITH 210° DISPLACEMENT. NONSTANDARD

In this connection, Figure 6-1, the primary windings have their NON-POLA commoned or wyed up. The secondary A ϕ voltage now lags the primary A ϕ voltage by 210 degrees.

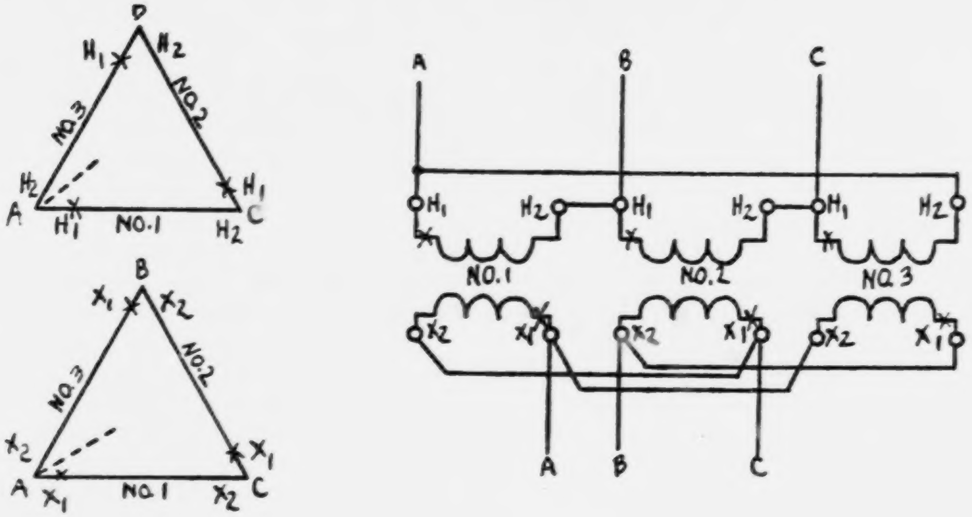

B
H1
H2
NO.3
NO.2
H2
H1
A
H1
NO.1
H2
C
B
X1
X2
NO.3
NO.2
X2
X1
A
X1
NO.1
X2
C
A
B
C
H1
H2
H1
H2
H1
H2
NO.1
NO.2
NO.3
X2
X1
X2
X1
X2
X1
A
B
C

Figure 6-m DELTA-DELTA CONNECTION WITH 0° ANGULAR DISPLACEMENT

Delta-Delta Connections. The delta-delta connection shown in Figure 6-m has been one of the most commonly used in the past. The three windings are connected in a series arrangement, the end of one primary winding is connected to the beginning of the next primary winding. The primary winding of each winding of each transformer is connected directly across the line voltage, and because of this the transformer coil winding and bushings must be rated for line voltage. This type of connection is most generally used with a delta power system, but may be applied on a wye power system. The line current in a delta-connected transformer bank is equal to 1.73 times the winding current. If one of the transformers in the bank should fail, secondary power can be supplied by reconnecting in open-delta for emergency service, in which case the rating of the bank will be 57.7 percent of the original bank rating.

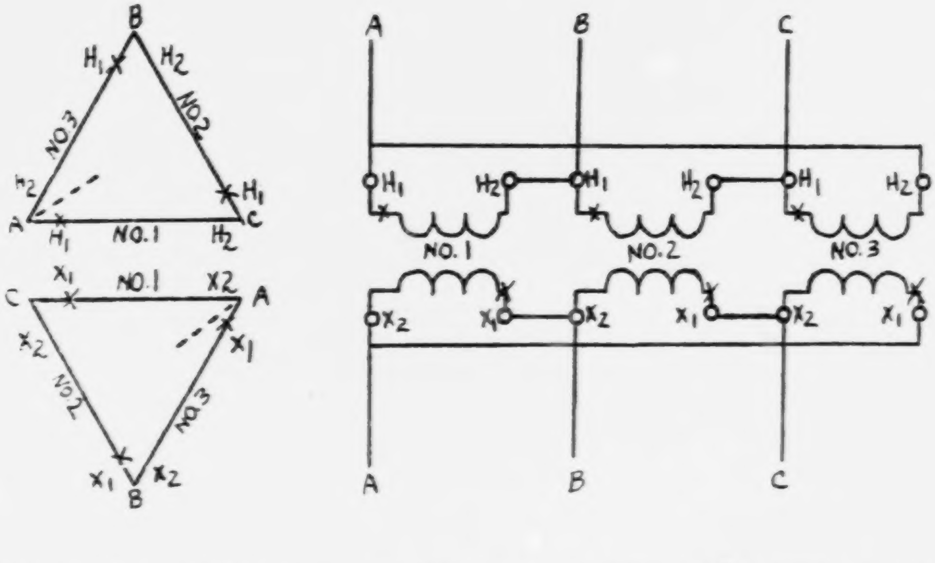

B
H1
H2
NO.3
NO.2
H2
H1
A
H1
NO.1
H2
C
C
X1
NO.1
X2
A
X2
X1
NO.2
NO.3
X1
X2
B
A
B
C
H1
H2
H1
H2
H1
H2
NO.1
NO.2
NO.3
X2
X1
X2
X1
X2
X1
A
B
C

Figure 6-n DELTA-DELTA CONNECTION WITH 180° ANGULAR DISPLACEMENT

The open delta is a two-transformer connection, used primarily on delta power systems. Its purposes are the same as the delta-delta, but it is used when only two transformers are available for supplying a three-phase load. The voltages impressed across the two windings are the same as in the delta-delta. The currents in the windings are changed because the current in two of the lines have only one path. The current in the windings is therefore equal to the line current.

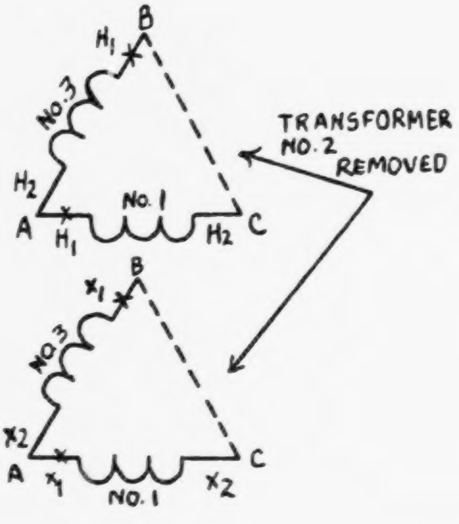

B
H1
NO.3
H2
A
H1
NO.1
H2
C
TRANSFORMER NO.2 REMOVED
B
X1
NO.3
X2
A
X1
NO.1
X2
C

Figure 6-o OPEN-DELTA CONNECTION

Delta-Wye Connection. Transformers can also be connected in a delta-wye arrangement. The delta primary and wye secondary is used for both step-up and step-down. Figure 6-p shows the connections for a delta-wye transformer bank used to step-up the voltage from a generating plant, the voltage coming out of the

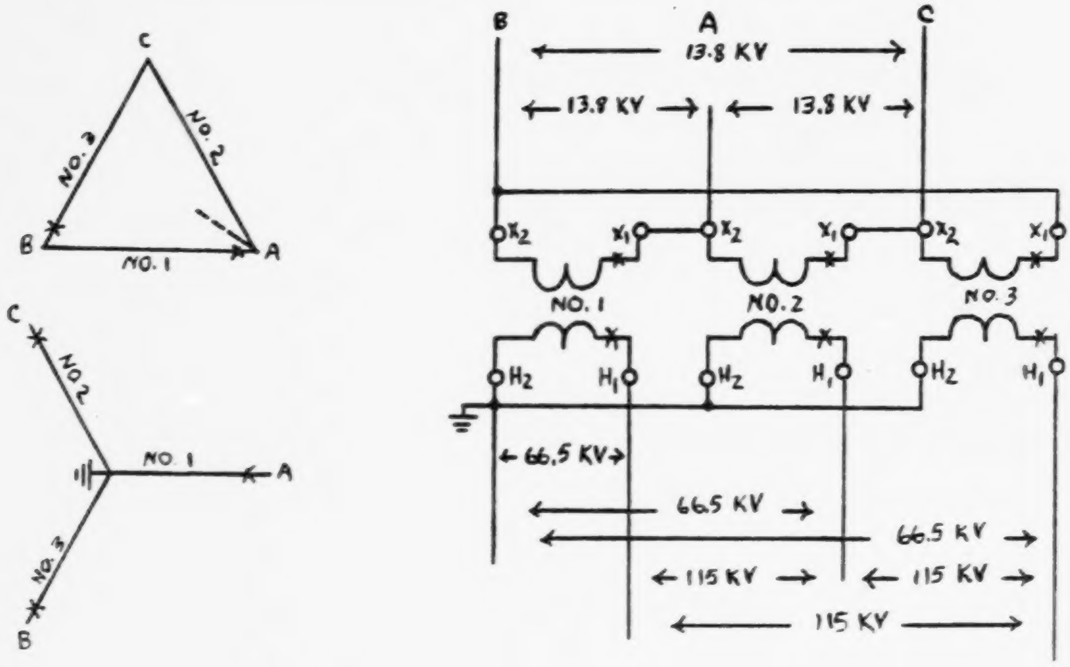

C
NO.3
NO.2
B
NO.1
A
C
NO.2
NO.1
A
NO.3
B
B
A
C
13.8 KV
13.8 KV
13.8 KV
X2
X1
X2
X1
X2
X1
NO.1
NO.2
NO.3
H2
H1
H2
H1
H2
H1
66.5 KV
66.5 KV
66.5 KV
115 KV
115 KV
115 KV

Figure 6-p DELTA-WYE CONNECTION WITH 30° ANGULAR DISPLACEMENT

generators at 13.8 kv and being stepped up to a transmission line voltage of 115 kv. This type of connection is well adapted for stepping up voltages. The input voltage is stepped up by the transformer ratio and is further increased by the factor of 1.73. The transformers each have a ratio of 13,800 volts to 66,500 volts. Each high-voltage secondary winding is connected between the secondary neutral and one of the three line wires. The voltage between the neutral and any one of the three line wires is the same as the secondary coil voltage or 66,500 volts. The voltage across the three line wires is 3 x 66,500 or 115,000 volts.

A wide variety of voltage-vector diagrams representing voltage relations for various transformer connections can be drawn. As commonly used, the straight line is drawn representing the physical winding of the transformer. As long as the vector is kept parallel to its original position, it can be moved at will to indicate its physical connection to other windings. In a three-phase transformer the time relations between the voltage are the same as for a single-phase transformer. In the normal application of voltage diagrams, an arrow on the vector or a polarity mark is unnecessary since the numbers on the vector give the required information. The high- and low-voltage leads on three-phase transformers which connect to the full-phase windings are marked H1, H2, H3, and X1, X2, X3, respectively. The full-phase winding of a tertiary winding is marked Y1, Y2, and Y3. A neutral lead is marked with the proper letter followed by 0 (H0, X0).

Three-phase Transformers. The three-phase transformer, sometimes referred to as polyphase, has three separate windings or electrical circuits, but has one common core structure all placed in a single case or tank. The connections between coil windings are made inside the transformer case. The three-phase transformer has some advantages over three single-phase transformers as the kva rating of the bank is increased. A three-phase transformer costs less; there is only one unit to install and connect; it occupies less space; it weighs less; and the connections are simple. The three-phase transformer, on the other hand, is not quite as flexible as the single-phase bank, and, in the very high voltage class, it is more economical because of insulation involved to construct the single-phase unit.

To simplify connections of the transformers, all leads brought out of the case or tank are marked by a system of letters and numbers, as mentioned, and appear on the diagram nameplates or connection diagrams which accompany the transformer. Markings are applied so that, with the sequence of voltage on the high-voltage side in the order H1, H2, H3, it will be X1, X2, X3 on the low-voltage side. Angular displacement between the high-voltage and low-voltage winding is the angle between the lines passing from the neutral point through H1 and X1, respectively, in the voltage-vector diagram. AIEE standards give three angular displacement groups for three-phase transformers.

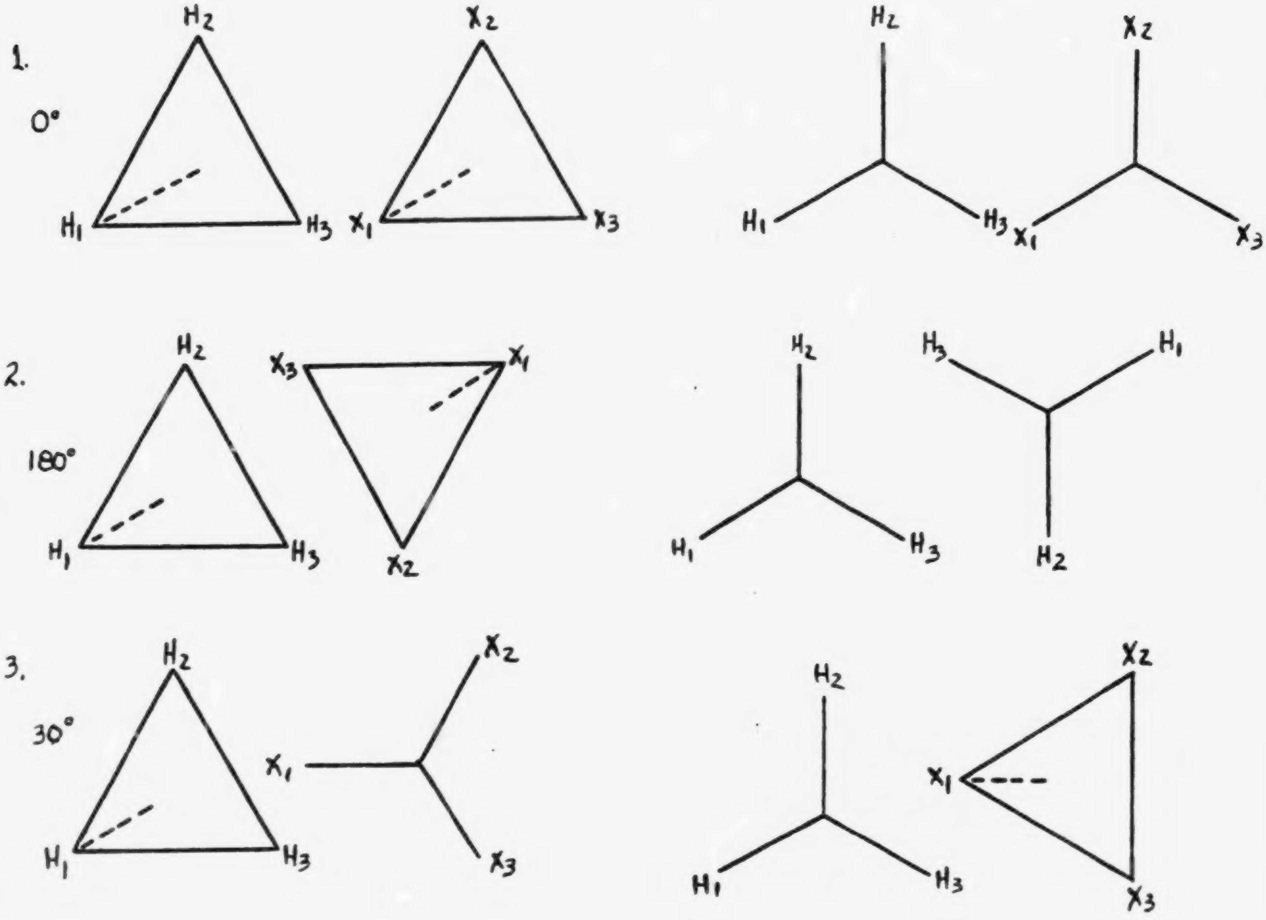

1.
0°
H2
H1
H3
X2
X1
X3
H2
H1
H3
X2
X1
X3
2.
180°
H2
H1
H3
X3
X1
X2
H2
H1
H3
H3
H1
H2
3.
30°
H2
H1
H3
X2
X1
X3
H2
H1
H3
X2
X1
X3

Figure 6-q LEAD MARKINGS AND VOLTAGE VECTOR DIAGRAMS FOR A FEW OF THE USUAL THREE-PHASE TRANSFORMER CONNECTIONS

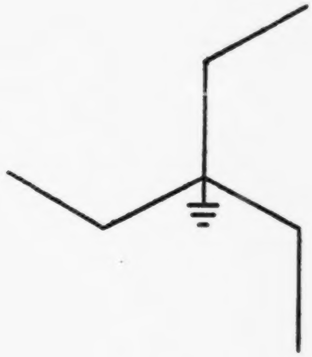
Groups 1, 2, and 3 have 0, 180, and 30 degrees, respectively.

Use of Delta Winding to Suppress Harmonics. When three transformers are connected in wye and operate as a three-phase bank, their voltages and their exciting currents are 120 degrees apart. If the neutral is not grounded or without a fourth neutral wire, the three leads supplying the transformers are carrying current to and from the transformer and the sum of the instantaneous currents must be zero. The third harmonic parts of the exciting current in each line cannot add up to zero, being three times the normal frequency, they are three times 120 degrees, or 360 degrees apart and, if this exciting current (third-harmonic) cannot flow, it will induce a distorted-voltage wave which will contain a thir harmonic component. Harmonic voltages are objectionable because they introduce an additional voltage stress between windings and ground and may be the cause of telephone interference. Grounding the neutral eliminates some of the above problem.

In three-phase transformers with wye-wye connections, it is common practice to provide a third winding connected in delta which provides a path for the third-harmonic exciting current to circulate around in. Such a winding is called a tertiary winding and it may or may not be used to supply external load in addition to its primary function of suppressing harmonics.

The Grounding Transformer. On delta power systems, it is sometimes desirable to provide a ground source in order to detect and thus limit the potential hazard of energized phase wires on the ground which expose the public to danger. Overhead systems are subject to disruption by automobiles, ice and windstorms. In the ungrounded system, the line conductors have capacitances between one another and to the ground. If one conductor becomes grounded, the voltage across the other two capacity branches will increase to phase-to-phase voltage which sometimes causes insulator failure.

In such cases, a grounding transformer is used. The grounding transformer carries no load, normally, and supplies current only if one of the lines becomes grounded. Usually a ground fault is detected by a relay operated either by the current in the ground lead or by the unbalance of line voltage which results, and the relay, in turn, operates a circuit breaker to disconnect the faulted line. Grounding transformers are usually wound "zig-zag" for economy, with no secondary winding.



ZIGZAG, OR INTERCONNECTED
WYE TRANSFORMER CONNECTION

Figure 6-r

Grounding transformers may be a wye-delta transformer with the neutral solidly grounded and the wye terminals connected to the phase wires of the delta system. In this case, the delta must be closed to provide a path for the zero-sequence currents which may be rather large in the event of a phase-to-ground fault on the high side. The delta winding may or may not be used to serve other loads. The wye winding must be of the same voltage rating as the circuit which is to be grounded.

Instrument Transformers. Instrument transformers are used for two reasons: first, to protect station personnel from contact with high voltage circuits, and second, to permit the use of instruments with a reasonable amount of insulation and reasonable current-carrying capacity. Direct measurements of high voltage or heavy currents would involve large and expensive instruments and relays in a wide variety of designs. The function of instrument transformers are to deliver to the instruments a current and voltage which shall be always proportional to the primary current and voltage, and not exceed a safe potential above ground. Generally, the secondary of a voltage transformer is designed for about 115 volts and the secondary of a current transformer for 5 amperes.

There are two general classes of instrument transformers: the potential transformer, and the current transformer. The potential transformer operates on the same principle as a power or a distribution transformer, only with lower ratings of 100 to 500 volt-amperes, with the low-voltage side usually wound for 120 volts. The load, or burden, consists of voltmeters, wattmeters, watthour meters, power factor meters, protective and regulating relays, to name a few. One transformer can be used for a number of instruments at the same time if the total current taken by the instruments does not exceed that for which the transformer is designed.

The current transformer is a special development of the transformer principle. It is designed so that its primary winding is in series with one of the line wires. The object is to maintain a constant ratio between the currents in the primary and secondary windings, instead of a constant ratio between voltages, which is the usual requirement. Current transformers are used with ammeters, wattmeters, power factor meters, watthour meters protective relays, and the trip coils of circuit-breakers. One current transformer can be used to operate several instruments provided the combined burden does not exceed that for which the transformer is designed and compensated.

The primary of a current transformer consists of one, or only a few turns of heavy wire wound on a laminated iron core. The secondary consists of more turns of smaller wire, wound on the same core as the primary. The current rating of the primary is the maximum value of current which the winding should normally carry. The secondary winding is always rated at 5 amperes. The instruments connected in the secondary circuit of the transformer are placed in series, so that the secondary current will pass through each instrument. In the potential transformer, the instruments are all connected in parallel. As instruments are added to the current-transformer circuit, higher voltage is required to force the current through the instruments. For this reason the secondary circuit of a current transformer must never be opened when current is flowing in the primary. Even a small value of primary current produces an excess of core flux and a correspondingly high secondary voltage. Voltages of several thousand volts are possible under open-circuit conditions. Absolutely no harm can come from short-circuiting the secondary of the current transformer and this should be done whenever the transformer is not to be used, or if it is necessary to change the circuit while it is energized.

Since a-c current is continually reversing its direction, one might well ask what is the significance of polarity markings. Its only significance is in showing the direction of current flow relative to another current or to a voltage. To connect instrument transformers to wattmeters, watthour meters, etc., it is necessary to know the relative instantaneous direction of currents in the leads. For this reason the leads of the primary and secondary are marked. The usual practice is to use the H1, H2, X1, X2 markings used in power transformers. The convention is that, when primary current enters the H1 terminal, secondary current leaves the X1 terminal. You may still find some transformers marked with a white polarity mark. When paint is used, the terminals corresponding to H1 and X1 are identified.

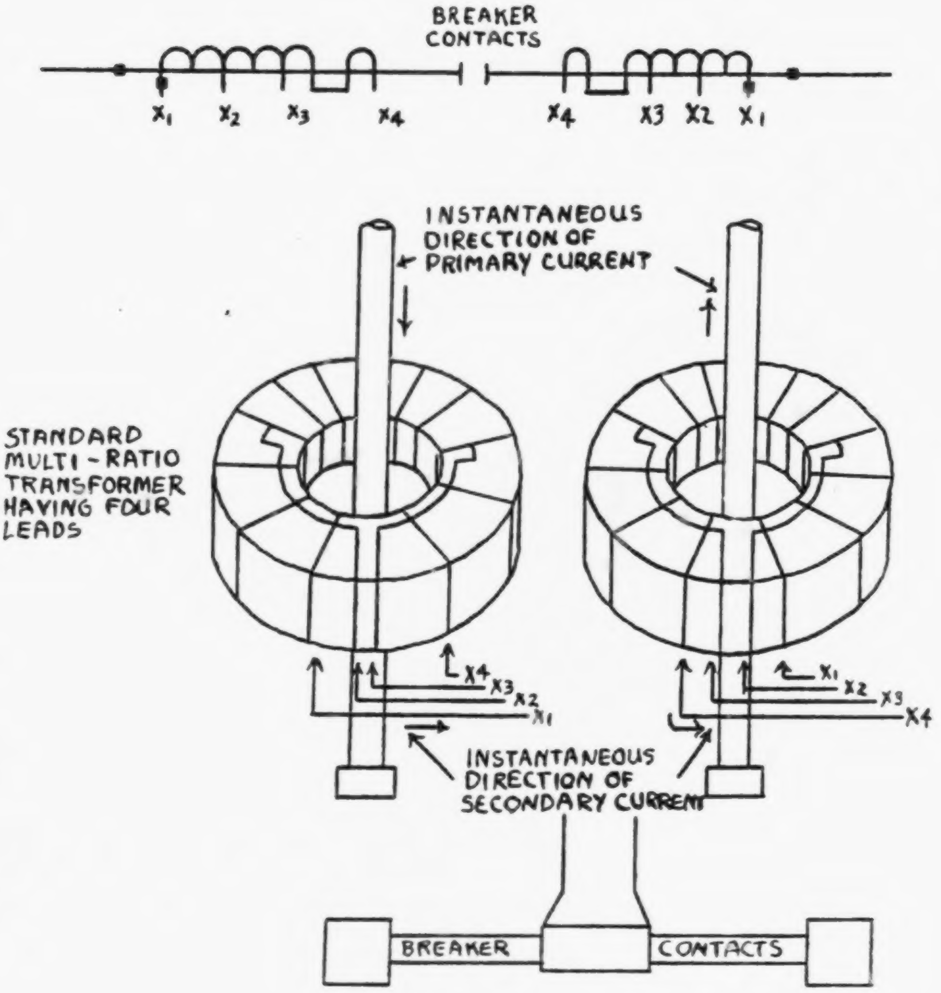
Instrument transformers are sometimes divided into three general classes depending upon their insulation. A dry-type is one in which the insulation consists only of solid insulating material. A compound-filled instrument transformer is one which is contained within a case, and in which the structural insulating material is supplemented by submergence in a solid or semi-solid insulating material introduced into the case in a fluid state. An oil-immersed instrument transformer is one which is contained within a case and in which the structural insulating material is supplemented by insulating oil in which the transformer is submerged.

There are many different designs employed in the construction of instrument transformers, but the three general types are the wound type, the through type, and the doughnut type. Through-type current transformers have no primary winding, but use the current carried by the cable or bus bar to energize the core. The simplest, of course, is the doughnut type, which can be slipped over the switch gear bus. Almost all large power circuit breakers utilize this type of C.T. installed in the bushings. The transformer is mounted over the terminal bushing and consists of ring-shaped iron punchings or a strip-wound steel core, around which is wrapped an insulated secondary winding.

The accuracy of bushing-type transformers is somewhat dependent on the number of ampere-turns in the transformer. Since there is only one primary turn, this amounts to saying that the larger the ratio, the better will be the accuracy. Since these C.T.'s are used for larger amounts of power, accuracy at small currents is not so important if they respond to the larger amounts. They are commonly used to operate relays, trip coils and meters in power substations, and their accuracy is normally satisfactory for this type of service.

Bushing type C.T.'s are often provided with several taps which can be connected to provide a choice of ratio. When shorting out a multi-ratio C.T., the short circuiting of any two leads effectively short-circuits the output of the entire transformer. It is obvious then that only one ratio can be used at a time. In Figure 6-s you will note that a ratio of 600 amperes to 5 amperes is available if the secondary taps X2 and X3 are used. The X1 tap, normally considered polarity, is not used, nor is the X4 terminal. When intermediate taps are used, the tap numerically nearest X1 has the same polarity as X1. The H1, or polarity on the primary, is normally installed toward the bushing terminal.

All instrument transformers should be grounded on the secondary side as an extra precaution against danger from the high voltage in case the insulation should be punctured by lightening or other abnormal stresses. In three-phase connections, any point of the secondary may be grounded, but it is preferable to use a neutral point or a common wire connection, and it is best to ground this to only one point, preferably at the switchboard.


BREAKER CONTACTS
X1
X2
X3
X4
X4
X3
X2
X1
INSTANTANEOUS DIRECTION OF PRIMARY CURRENT
STANDARD MULTI-RATIO TRANSFORMER HAVING FOUR LEADS
X4
X3
X2
X1
X1
X2
X3
X4
INSTANTANEOUS DIRECTION OF SECONDARY CURRENT
BREAKER
CONTACTS

TYPICAL BUSHING TYPE CURRENT TRANSFORMER POLARITY LEAD MARKING-CONNECTION FOR OIL CIRCUIT BREAKER

Figure 6-s

CONNECTION CHART

MARKED RATIO	TURN RATION	SECONDARY TAPS
200 to 5	40 to 1	X1 - X2
400 to 5	80 to 1	X3 - X4
600 to 5	120 to 1	X2 - X3
800 to 5	160 to 1	X1 - X3
1200 to 5	240 to 1	X1 - X4

Several Words of Caution. Never fuse the secondary circuit of a C.T. and never open the secondary of a C.T. in an energized circuit.

A current-transformer secondary should be kept shorted, even in storage. Never short-circuit the secondary terminals of a potential transformer. A short-circuited potential transformer will burn out in a few seconds since the reaction is the same as that of a short-circuited distribution transformer.

An instrument transformer secondary should always be well grounded, so as to limit the possibility of high voltages.

A possible cause of high voltage in a C.T. or P.T. secondary is electrostatic induction from the high-voltage winding if the secondary is not grounded. It is possible to have voltages between the grounded secondary and ground of from 15 to 30 percent of the circuit voltage to ground.

The transformer acts as a capacitance voltage divider and, although there is little energy back of this voltage, the person or persons working on the secondary circuits who come in contact with such a potential could receive a severe injury.

Some Points to Remember. In a delta-connected system, three-wire, three-phase:

a. The coil winding of the transformer and the line voltage are equal.

b. The line current is equal to 1.732 times the current in the transformer winding.

c. The current in the delta connected winding of a transformer is equal to the line current divided by the square root of 3, or times 0.58.

d. $I = \frac{P}{1.732 \times E \times \cos \theta}$

e. For balanced loads

$P = 1.732 \times E \times I \times \cos \theta$

Where: E = ϕ-ϕ voltage

I = current in line

P = power in watts

cos θ = power factor

In a wye-connected system, four-wire, three-phase:

a. The line voltage is equal to 1.732 x transformer coil voltage.

b. The coil winding and line currents are equal.

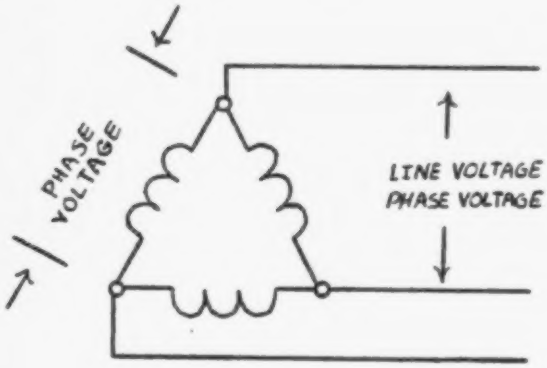
c. $T = \frac{P}{3 \times E \times \cos 0}$

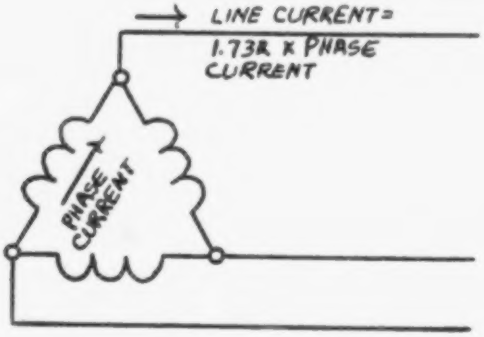
d. For balanced loads:

$P = 3 \times E \times 1 \times \cos 0$

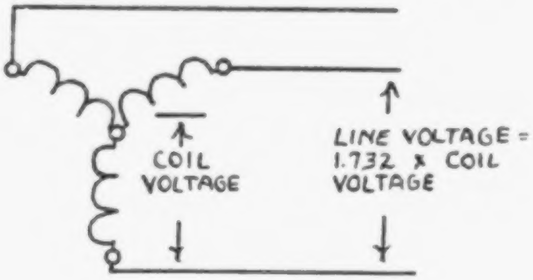
Where: E = 0-N voltage
I = current in line
P = power in watts
cos 0 = power factor

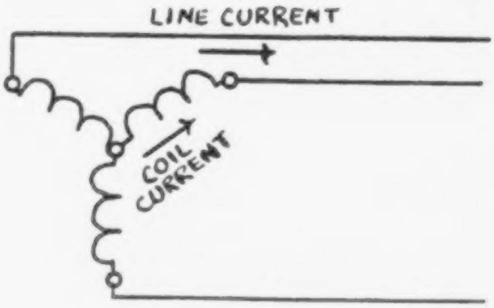
DELTA


PHASE VOLTAGE
LINE VOLTAGE = PHASE VOLTAGE


LINE CURRENT = 1.732 x PHASE CURRENT
PHASE CURRENT

WYE

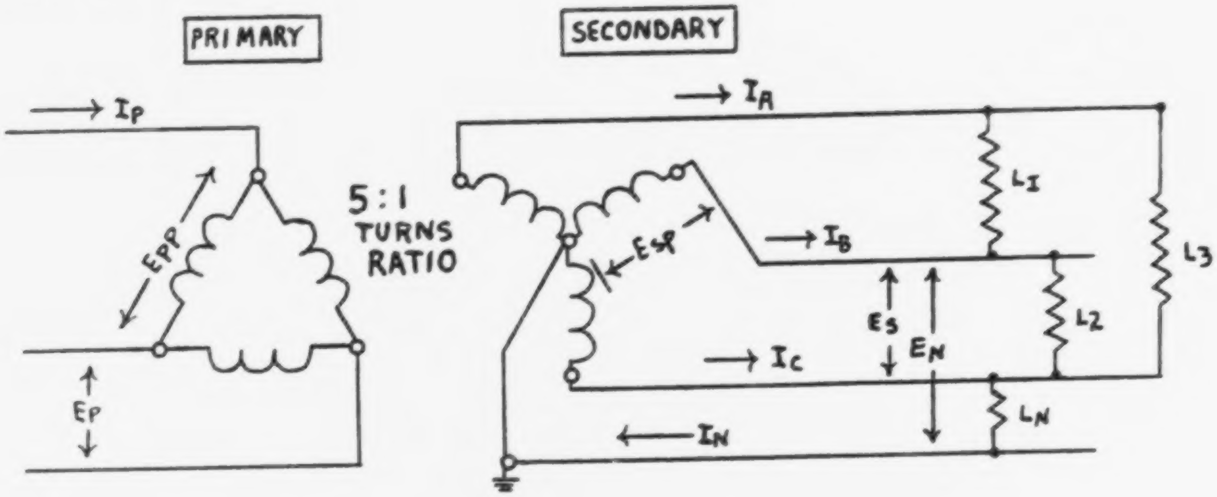

COIL VOLTAGE
LINE VOLTAGE = 1.732 x COIL VOLTAGE


LINE CURRENT
COIL CURRENT

Lesson 2-4-15

TRANSFORMER CONNECTIONS AND INSTRUMENT TRANSFORMERS

Check-up: (2-4-15)


PRIMARY
SECONDARY
$\rightarrow I_P$
$\rightarrow I_A$
E_{PP}
5:1 TURNS RATIO
E_{SP}
$\rightarrow I_B$
L_I
L_3
E_S
E_N
L_2
$\rightarrow I_C$
E_P
L_N
$\leftarrow I_N$

1. If E_{pp} = 500 volts, then E_p = ______________________________?
2. If E_{pp} - 865 volts, then E_s = ______________________________?
3. If E_p = 1045 volts, then E_{sp} = ______________________________?
4. If E_n = 120 volts, then E_{sp} = ______________________________?
5. If E_s = 480 volts, then E_n = ______________________________?
6. If E_n = 277 volts, then E_p = ______________________________?
7. If I_p = 100 amps, then I_{pp} (through E_{pp}) = __________________?

8. If load is balanced and I_p = 58 amps, then I_B = ________________?

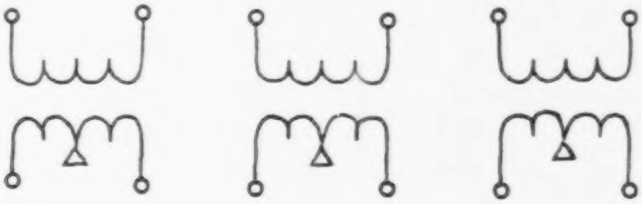
9. If $L_1 = L_2 = L_3$ and $L_N = 0\Omega$, then $I_N = 0$. True or false?

10. If $L_1 = L_2 = L_3 = L_N$, then $I_A = I_B = I_C$. True or false?

Check-up: (2-4-16)

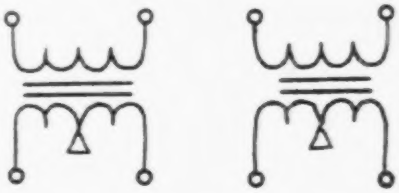
1. Why are instrument transformers used?
2. What are some advantages of a single-phase, three-wire circuit?
3. What is the difference in single and polyphase transformers and what advantage has each type over the other?
4. What polarity is most common in: (a) a power transformer; (b) a distribution transformer; (c) and instrument transformer?
5. What is a transformer with a tertiary winding and what purpose does this winding serve?
6. What is a transformer with taps and what is their purpose?
7. Are the taps located near the end or in the center of the winding?
8. What problem is created by connecting a three-phase bank of transformers wye-wye and how is it overcome?
9. How are transformer leads marked?
10. Explain what is meant by "additive" and "subtractive" polarity.
11. List three requirements which should be observed if two transformers of equal kva capacity are to be connected in parallel so they will share the load.
12. Can transformer taps be changed under load?
13. Make a connection diagram that shows how a transformer bank is connected for supplying a 240-volt, three-wire, three-phase system from a 2400-volt, three-phase source. Use single-phase transformers with additive polarity,

rated 2400/240 volts at 100 kva. Mark the polarity of all transformer leads.



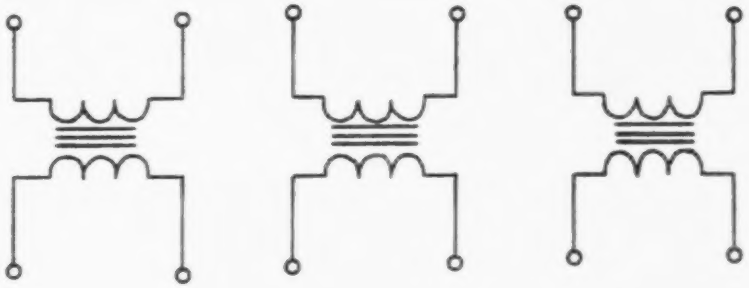
14. A balanced load of 200 kw at 0.80 lag power factor is supplied by the transformer bank in problem 13. What is the primary line current? The secondary line current?

15. If one of the transformers in problem 13 were damaged and had to be removed, show how you would re-connect the remaining two, so as to maintain service.



16. What is the maximum balance load in kw of power factor 0.80 lag which could be connected to the transformer bank during the emergency described in question 15?

17. Make a connection diagram for three single-phase, 50 kva, 2400/120-volt transformers with additive polarity to supply a four-wire, three-phase service of 120/208-volts that can supply both 120-volt single-phase lighting service and 208-volt, three-phase motor load. Show the high side of the bank connected to a 2400/4160-volt, three-phase primary.



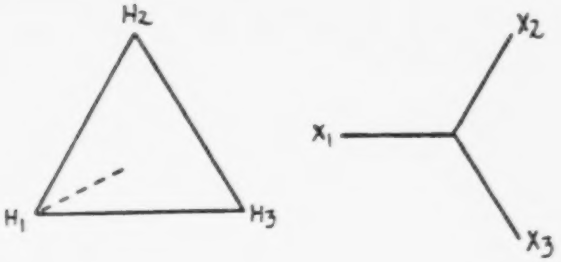
18. If the power factor of the load is 0.80 what is the maximum balanced three-phase load that should be connected to the bank described in question 17?

19. A three-phase, wye-connected transmission line has a voltage of approximately 60.5 kv across the three line wires and 35 kv from each line to ground. Make a connection diagram showing how to connect three transformers rated at 35,000 to 11,000 volts, 2,000 kva, with subtractive polarity so as to step the transmission voltage down to supply energy to an 11,000-volt, three-phase, three-wire distribution system.

20. What is the line current on the secondary side when the transformer in question 19 is loaded to rated capacity? Neglect any losses.

21. What is the line current on the primary side when the transformer in question 19 is loaded to rated capacity? Neglect any losses.

22.

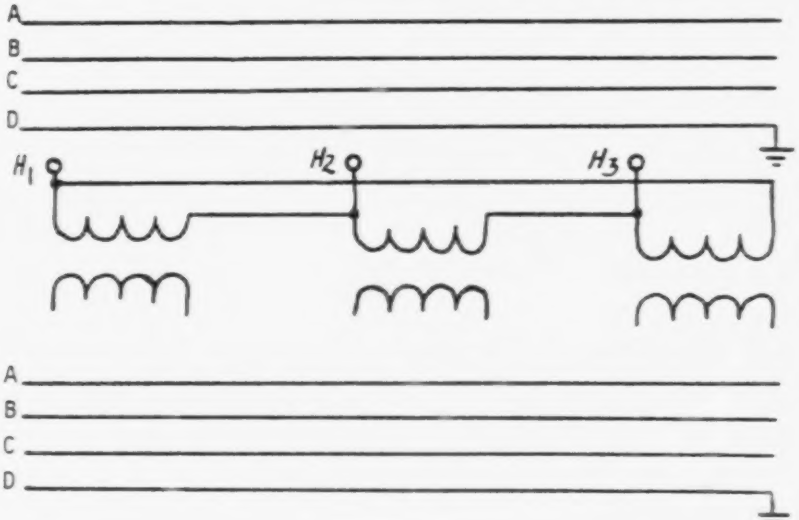


15,000 kva transformer

63,350/126,700 - 13,200/7200 volt

TAP	H.V.	L.V.
1.	66700	13200 volts
2.	65025	
3.	63350	
4.	61675	
5.	60000	

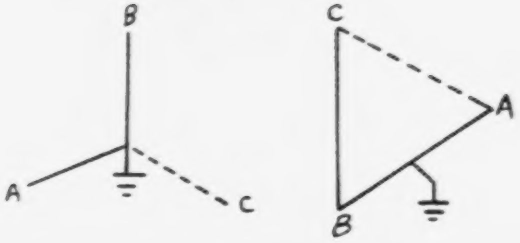
Complete the connection diagram for the above transformer if it is to be connected to a three-phase wye system having 57,000 volts across the three-phase wires and 33,000 volts from each phase to ground. The secondary is to supply energy to a three-phase wye distribution system having approximately 12,400 volts across the three-phase wires and 7,160 volts from each phase to neutral. What tap is the transformer to be set on?



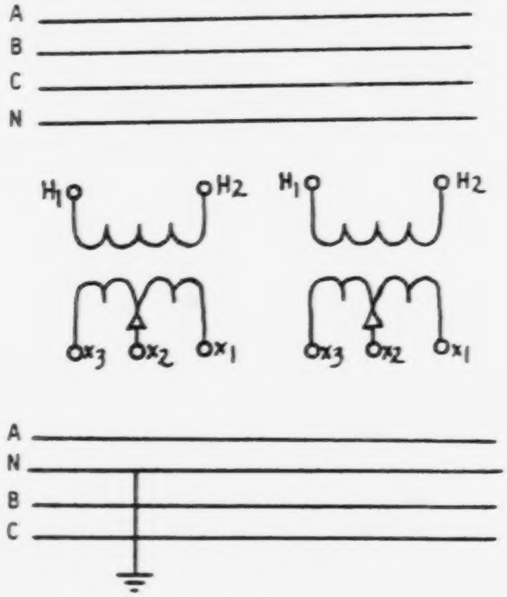
23. If, in question 22, the voltage is low and you are asked to change the taps, would you move the tap changer to a higher or lower tap number?

24. If a transformer is rated at 150 kva, what would be its kw rating at 80 percent power factor?

25. Complete the connections for a three-phase open-wye open-delta for 120/240 service as shown in the voltage diagram. This bank can then be used to supply large single-phase 240 volt and 120/240 volt loads with small amounts of three-phase loads.



210° ANGULAR DISPLACEMENT



ELECTRICAL THEORY

UNIT V

METERS AND INSTRUMENTS

This unit contains the following lessons:

ELECTRICAL MEASURING INSTRUMENTS

Lesson 2-5-1: Meter Construction and Meter Movements
Lesson 2-5-2: Meter Characteristics and Multirange Ammeters
Lesson 2-5-3: Voltmeters - Ohmeters and Megohmeters
Lesson 2-5-4: Power Meters and Vacuum-Tube Voltmeters
Lesson 2-5-5: Bridge Circuits and Voltage Dividers

ELECTRICAL MEASURING INSTRUMENTS

You are to acquire from your study of the following lessons:

1. An understanding of the principles and operation of basic meter movements.
2. The use and application of a few of the more common instruments that are normally used in the power industry.
3. An understanding of how power is measured.
4. The theory and application of multirange instruments.

Directions:

1. It is recommended that the instructor permit the members of the class to connect and become familiar with some of these instruments in an electrical lab class session, to take readings and also to calculate the resistance, impedance, volt-amps, watts, etc., of several coils, resistances and typical electrical loads as may be available.
2. Read any additional references that are assigned by your instructor.
3. Write and hand in the answers to all the check-up questions.

Lesson 2-5-1

METER CONSTRUCTION AND METER MOVEMENTS

Required references:

Electricity One-Seven,

Basic Mathematics for Electricity and Electronics,

Check-up: (2-5-1)

--

1. What are the two basic types of current meters?
2. If the current through a coil is increased, what happens to the magnetic field around the coil?
3. What is another name for the moving-coil meter?
4. What are the three types of moving-iron meter movements?
5. What basic parts are common to most meter movements?
6. Explain the difference between a hot-wire ammeter and a thermocouple meter.
7. Explain why two springs are used in meter movements and how changes in temperature are compensated for?
8. Explain the principle and function of the zero-adjust screw.
9. If the current through a moving-coil meter doubles, by how much does the pointer deflection increase? Do moving-iron meters react the same? Explain any difference in the scales for the two meters.
10. What is meant by damping in a meter? Why is it necessary?

Lesson 2-5-2

METER CHARACTERISTICS AND MULTIRANGE AMMETERS

Required reference:

Electricity One-Seven,

Check-up: (2-5-2)

1. Define meter sensitivity. What is its significance?
2. Why can't the basic moving-coil meter measure a-c?
3. Why is it desirable for a-c meter to indicate rms values?
4. Why is a rectifier meter less accurate than a basic moving-coil meter?
5. What type of meter is used to measure high-frequency current?
6. Why are external shunts used with meters designed to measure very large currents?
7. What is a multirange meter? What is the advantage of such a meter?
8. What is meant by "observing polarity" when connecting a current meter?
9. Why should a current meter never be connected in parallel with a power source or load?
10. Should a 95-milliampere current be measured with the 0-10 milliamperes, 0-100 milliamperes, or 0-1 ampere range of a multirange meter? Explain your reason.

Lesson 2-5-3
VOLTMETERS--OHMMETERS AND MEGOMMETERS

Required references:

Electricity One-Seven,

Basic Mathematics for Electronics and Electricity,

Check-up: (2-5-3)

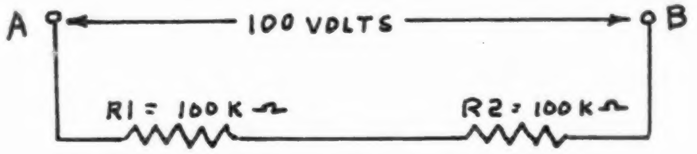
1. Explain how a current meter movement can be made to measure voltage.

2. Why are multiplier resistors used in voltmeters and shunt resistors used in ammeters?

3. A 0 to 1 milliampere meter movement has a coil resistance of 1,000 ohms. What value of multiplier resistor is needed to measure 100 volts?

4. What is meant by the ohms/volt rating of a voltmeter and what is the relationship between a meter's ohm/volt rating and the current required for full-scale deflection?

5.



   a. Calculate the voltages that would exist across R^1 and R^2 in the circuit shown here.
   b. If a 0 to 100 voltmeter with a sensitivity of 1,000 ohm per volt were to be connected across R^1, what would the voltmeter read?

6. If in question 5, a 0 to 100 voltmeter with a sensitivity of 20,000 ohm per volt is used: (a) What would the voltmeter read? (b) What would the voltmeter read if it is connected across points A and B? (c) When the voltmeter is connected across points A and B, what current flows through R^2?

7. a. What is the basic difference between series and shunt ohmmeters?
   b. What is the purpose of the zero-ohm set control?

8. What might be the result of making resistance measurements on a circuit while the circuit is energized?

9. What are wheatstone bridges used for? Must the circuit be deenergized before applying this device?

10. What is a megger and for what purpose is it used? Will it measure resistance? Explain.

Lesson 2-5-4
POWER METERS AND VACUUM-TUBE VOLTMETERS

Required reference:

Electricity One-Seven,

Additional information:

The operation of the permanent-magnet moving-coil instrument was studied earlier in this lesson. The application of this principle in electrical measurement is credited to d'Arsonval-Deprez. Most instruments for the measurement of direct current and voltage utilize a permanent-magnet moving-coil-type element and therefore are commonly called d'Arsonval movement meters.

The electrodynamic type instruments depend for their operation upon the reaction between the current in one or more moving coils and the current in one or more fixed coils. The dynamometer element provides a versatile tool for many types fo a-c measurement and is extensively used for mesurement of power, as well as for the current and voltage.

Before starting to take a reading on a meter, it is necessary to know the value of each division on the scale. To determine this, look at the scale on which the instrument is being used. For example, a voltmeter may be connected to the 0-150-volt or 0-300-volt scale. Next, note the number of divisions between any two numbers on the scale. Thus, if the voltmeter were connected to the 0-150-volt scale and there were ten divisions between the 110- and 120-volt readings, then each division would equal one volt. Likewise, if the voltmeter were connected to the 0-300-volt scale, each division would equal 2 volts. When reading the very low or very high values on the scale, note the major subdivisions between the numbers as they do not always have the same value as in the middle of the scale.

If there is a mirror on the instrument, a reading may be more accurately made by closing one eye and then moving the head so that the reflection of the needle pointer cannot be seen in the mirror. This method enables one to look squarely at the meter.

In cold or dry weather, be careful not to rub the glass covering the instrument dial as this will create a static charge on the glass and may cause a false reading on the instrument. If the instrument glass does become charged, the charge can be dispelled by breathing on the glass.

When connecting instruments, it is often desirable to have someone check your connections before the power is turned on. A mistake in connections may cause the loss of an instrument, or a piece of apparatus, or injury to an employee.

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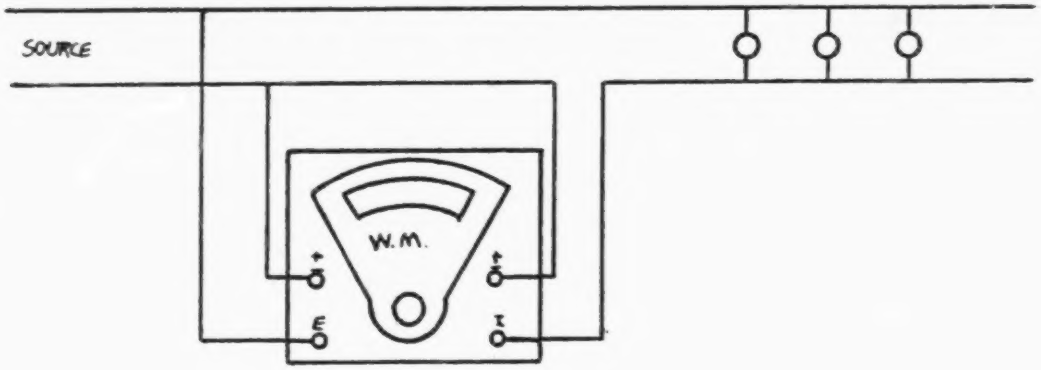
In the electrodynamic wattmeter, the moving element carries a pair of coils excited by the potential. The field is produced by the current flowing through coil. The field flux is proportional to the line current, the armature flux is proportional to the line voltage, and the instantaneous torque of the instrument is proportional to the instantaneous product of line current and voltage.

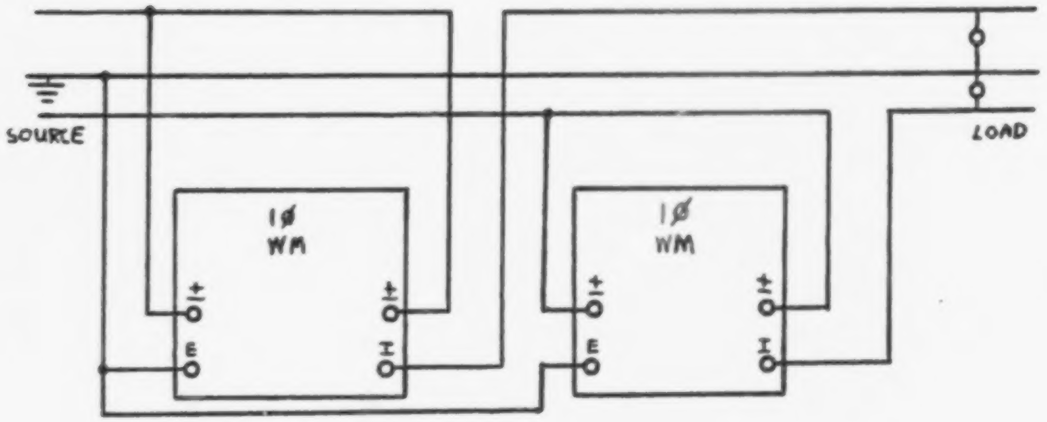
When using a multiple-range instrument to measure unknown power, the highest range should be tried first. If the indication is too low, a lower scale may then be used. It is advisable to protect wattmeters from overload by first trying the circuit with voltmeters and ammeters.

When connecting the wattmeter, the post of the potential circuit should always be connected to the same side of the line as the current's leads. This is necessary to prevent electrostatic forces between the armature and surrounding parts.



In the above external connection diagram for a wattmeter in a single-phase, two-wire circuit, the wattmeter measures the power loss in its own current circuit plus the power in the load. Some wattmeters are compensated for their own power losses so that only the power dissipated in the circuit is measured. If not, this loss can be subtracted out directly, when the precision of the results warrants, as it is usually marked on the meter.

For power measurement in the three-wire, single-phase circuit extensively used on domestic service and low-power industrial service, two dynamometer elements are required, or two readings must be taken.



EXTERNAL CONNECTION DIAGRAM FOR TWO WATTMETERS
IN A SINGLE-PHASE, TWO-WIRE CIRCUIT (120-240 VOLT)

Note that the current coil in the above diagram is not connected in the neutral wire, which carries only the unbalanced current. The total power in the circuit equals the sum of the total readings of the two wattmeters.

Because the power indications of the two elements are to be added, it is possible to combine them in a single instrument whose scale indicates the sum of the power indicated by the two elements.

Check-up: (2-5-4)

Write out the answers to the following review questions taken from Electricity One-Seven:

1. How else can power be measured besides by use of a wattmeter?
2. What are the advantages of using a wattmeter to measure power?
3. What is a compensated wattmeter?
4. Draw the schematic diagram of a basic wattmeter.
5. If the wattmeter is not compensated and its power loss is not indicated on the scale, how can its power loss be determined?
6. What is a multimeter?
7. What is a VTVM?
8. What is the advantage of a VTVM over a regular voltmeter?

Lesson 2-5-5

BRIDGE CIRCUITS AND VOLTAGE DIVIDER PROBLEMS

Required reference:

Basic Mathematics for Electricity & Electronics,

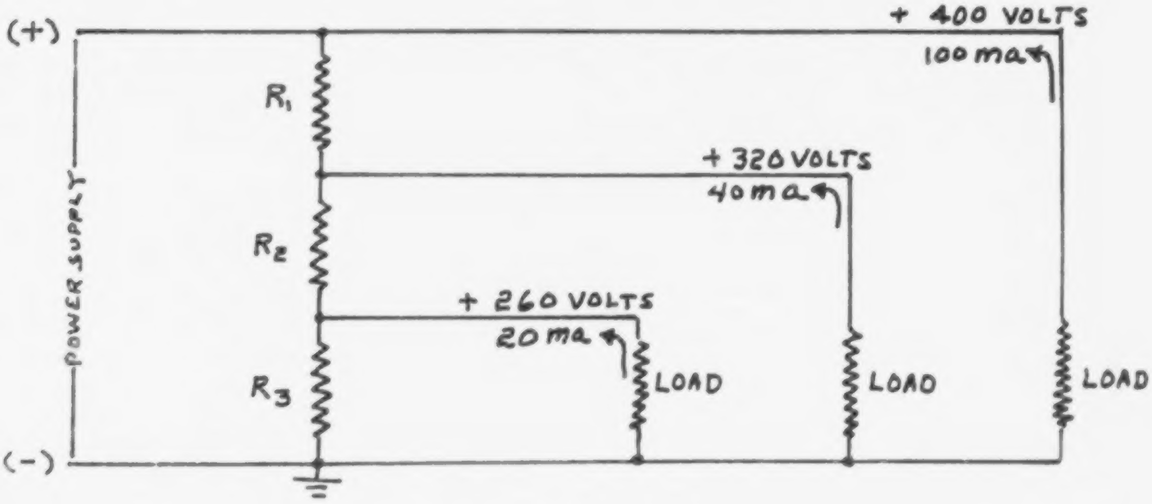
Check-up: (2-5-5)

1. A 0 to 50 microammeter has an internal resistance of 1,170 ohms. If this meter is shunted with a 130-ohm resistor, what must the meter reading meter be multiplied by, to obtain the correct value of current?

2. A 0 to 1 milliammeter has an internal resistance of 55 ohms. What shunt resistance is required to extend the range of the meter: (a) 0 to 10 ma? (b) 0 to 50 ma? (c) 0 to 500 ma? (d) 0 to 2 amp?

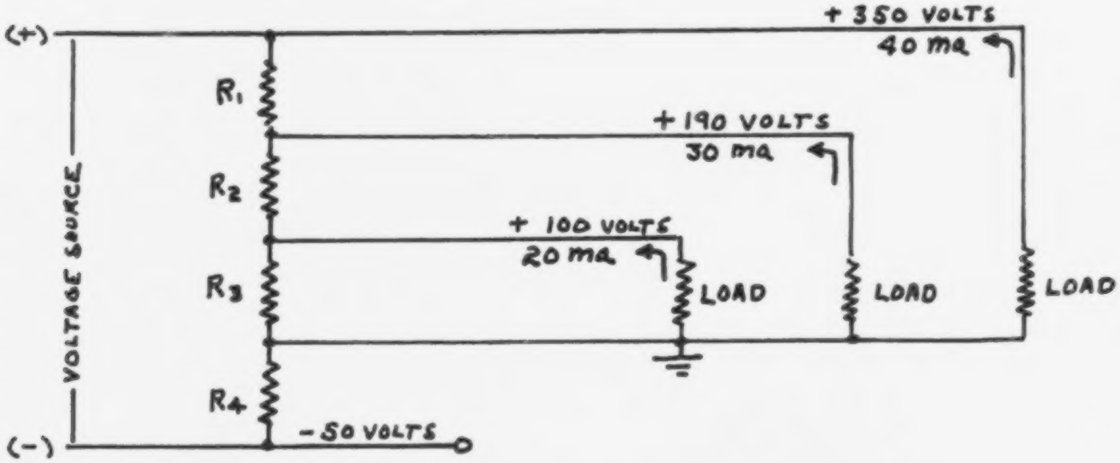
3. The 0 to 1 milliammeter in question 2 could be made to operate as a voltmeter by adding a series resistor. What value of series resistance must be connected in series to give the meter a range of: (a) 0 to 10 volts? (b) 0 to 150 volts?

4. What are the values in ohms for the resistors R_1, R_2, and R_3 in the voltage divider circuit shown below? A total of 180 ma is drawn from the power supply?



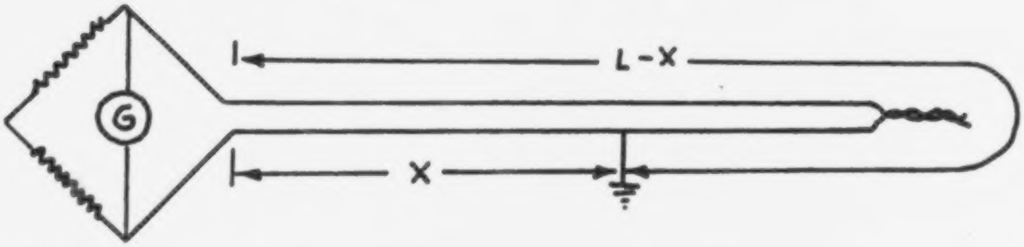
5. In the problem given for question 4, how much power is expended in: (a) R_1? (b) R_2? (c) R_3?

6. What are the values of the voltage divider resistors for the circuit shown below, if the bleeder current is 10 ma?


(+)
(-)
VOLTAGE SOURCE
R₁
R₂
R₃
R₄
+ 350 VOLTS
40 ma
+ 190 VOLTS
30 ma
+ 100 VOLTS
20 ma
LOAD
LOAD
LOAD
- 50 VOLTS

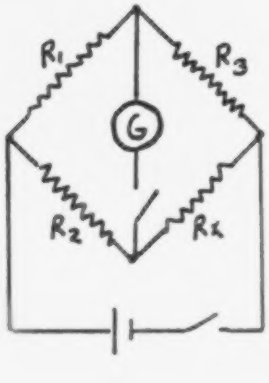
7. What wattage rating should be used for the voltage divider in question 6?

8. If the resistor R_4 became open circuited in problem 6, what would be the voltage between the negative terminal of the voltage source and ground?



9. The murry loop (shown above) is set up to locate a ground that exists in one conductor of a lead-covered No. 14 pair. The pair is tied together at the far end. When the bridge circuit is balanced, R_1 = 18.7 ohm and R_2 = 13.2 ohm. If the cable is 4,500 feet long, how far from the test end is the grounded point?

10. In the wheatstone bridge arranged as shown here, if R_1 = 0.001 ohm, R_2 = 1 ohm, and R_3 = 28.7 ohm, what is the value of R_x?



ELECTRICAL THEORY

UNIT VI

POWER SOURCES

This unit contains the following lessons:

BATTERIES

Lesson 2-6-1: Batteries
Lesson 2-6-2: The Lead-Acid Cell and Other Voltaic Cells
Lesson 2-6-3: Battery Circuits
Lesson 2-6-4: Care and Maintenance of Lead-Acid Storage Batteries

D-C GENERATORS

Lesson 2-6-5: The D-C Generator
Lesson 2-6-6: D-C Generator Construction

A-C GENERATORS

Lesson 2-6-7: The A-C Generator
Lesson 2-6-8: A-C Generator

BATTERIES

A study of the lessons that follow would provide you with:

1. A knowledge of some of the more common devices that produce electricity.
2. The action that the theory of all batteries is based on.
3. The general types of batteries in common use.
4. Storage batteries, their operation and care.

Directions:

1. Study the references thoroughly and familiarize yourself with all new words, terms, and definitions.
2. Read the additional references that may be assigned by your instructor.
3. Keep your notebook up to date.
4. Write out and hand in to your instructor the answers to all the check-up questions following each topic of the information sheet.

Lesson 2-6-1
BATTERIES

Required reference:

Electricity One-Seven,

Check-up: (2-6-1)

1. Do storage batteries actually store electricity? Upon what action is the theory of all batteries based?

2. What is a dry cell? What is a wet cell?

3. Name three common types of dry cells. Can a dry cell be rejuvenated?

4. Will a storage battery produce a flow of electric current before it is charged?

5. Will a storage battery, fully charged, remain in that condition if left on an open circuit?

6. Does the temperature have any effect on the output of a battery?

7. What is the composition of the electrodes and electrolyte of an uncharged lead-acid cell?

8. What is the purpose of vent holes in secondary batteries?

9. Can the condition of a storage cell be determined by checking the voltage of the cell on an open circuit?

10. What damage can result from lighted matches or other sources of fires in a battery room?

Lesson 2-6-2

THE LEAD-ACID CELL AND OTHER VOLTAIC CELLS

Required references:

Electricity One-Seven,

Check-up: (2-6-2)

1. What is the output voltage of a lead-acid cell at the instant the charging current is removed?
2. What is the specific gravity of a fully-charged lead-acid cell?
3. Can a-c be used to charge a storage battery? If so, how?
4. What is sulfation?
5. Why must distilled water periodically be added to a lead-acid storage battery?
6. In an alkaline secondary cell, is there a relationship between the specific gravity of the electrolyte and the state of charge of the cell?
7. What are the advantages of an alkaline cell over a lead-acid cell?
8. How is the current rating of a battery specified?
9. A battery has an ampere-hour rating of 80. What continuous current can it supply for ten hours?
10. What is a solar cell? What is a thermoelectric cell? What is a photocell?

Lesson 2-6-3
BATTERY CIRCUITS

Required reference:

Electricity One-Seven,

Additional information:

The e.m.f. of a cell on open circuit is always greater than when a cell is supplying current. This drop in voltage is due to the current flowing the internal resistance of the cell. There is always a drop in voltage when current flows through a resistance.

Discharge voltage = (e.m.f. of cell) - (I x R drop of cell)

All cells have some internal resistance. The internal resistance of a cell depends on the area of the plates that is exposed to the eletrolyte, the distance between the plates, and the temperature and density of the electrolyte.

A storage cell is like any other mechanical or electrical device in that it is impossible to get out of it all the energy imparted to it. The efficiency of a lead acid, for example, is approximately 75 percent. The loss of energy is due largely to the internal resistance of the cell caused by the I^2R loss.

The question is often raised: "How could you obtain a maximum current output from a given number of cells? Should they be connected in parallel or in series?" As a general rule, the cells should be so arranged that the total internal resistance of the battery will be equal to (or nearly as possible) the resistance of the external circuit. To do this it is sometimes necessary to resort to a series-parallel circuit which may consist of several groups of cells connected in series and the groups then connected in parallel. Primarily, however, when the resistance of the external circuit is high, the greatest current will be obtained by connecting the cells in series. When the external resistance is small, the greatest current will be obtained by connecting the cells in parallel.

Check-up: (2-6-3)

1. If a 12-volt battery has an internal resistance of 0.1 ohm, what is its output voltage when supplying a current of 10 amperes?
2. What is the output voltage of four 12-volt batteries connected in series aiding? What is the output voltage if they are connected in parallel?

3. If a storage battery which has an efficiency of 75 percent is charged with 1,000-kilowatt hours of energy, what should be the amount of energy that can be recovered on discharge?

4. What is the internal resistance of a cell which has a terminal voltage of 2.00 volts when discharging at a 12-ampere rate and the e.m.f. of the cell is measured at 2.05 volts?

5. The e.m.f. of a cell is 1.5 volts, and its internal resistance is 0.2 ohm. When current is supplied to a circuit, the voltage drop across the internal resistance of the cell is 0.3 volt. (a) What is the terminal voltage? (b) How much current flows in the circuit?

6. A cell, whose e.m.f. is 1.4 volts and internal resistance is 0.2 ohm, is supplying 1.5 amp to a circuit. (a) What is the resistance of the external circuit? (b) How much power is lost in the cell?

7. A high-resistance voltmeter reads 2.0 volts when placed across a cell that is connected to no other circuit. When the cell is delivering 5 amps to a circuit, the voltmeter indicates a terminal voltage of 1.1 volts. (a) What is the internal resistance of the cell? (b) What is the resistance of the external circuit?

8. A cell that is delivering 0.25 amps has an internal resistance of 0.5 ohm. The e.m.f. of the cell is 1.6 volts. (a) What is the terminal voltage? (b) What is the resistance of the external circuit? (c) How much power is expended in the cell?

9. Six cells are connected in series to a load of 8.4 ohms. Each cell has an e.m.f. of 1.5 volts, and the internal resistance of each cell is 0.1 ohm. (a) What is the circuit current? (b) How much power is expended in the battery?

10. If the cells of problem 9 are connected in parallel, what is the circuit current?

Lesson 2-6-4

CARE AND MAINTENANCE OF LEAD-ACID STORAGE BATTERIES

Required references:

American Electricians' Handbook,

Electricity One-Seven,

Additional information:

Normal Cell. The positive plates are normally dark brown. The negative plates should be uniformly gray. No visible change in the color of the plates occurs when the cell is discharged a normal amount. The cell temperature does not rise much, if any, on short heavy discharges.

Sediment should accumulate at a very slow rate. A normal charging program will result in a sparse, dark-brown sediment which in turn changes to gray. The sediment should never be white or lumpy if the charging program is correct.

Pilot Cells. Daily specific gravity reading should be taken on one cell which represents the condition of the entire battery. A battery is no better than the weakest cell, so the cell in the best condition is not chosen as the pilot cell. Neither should the worst cell be chosen as the pilot cell since it may be necessary to replace it before the entire battery is replaced.

A logical choice for a pilot cell would be the most convenient one for inspection from the medium low cells determined by the drop of specific gravity from the earliest records available to the time of selection of the pilot cell.

The pilot cell should have a vent-type hydrometer and thermometer to avoid loss of acid while reading specific gravities. Once a pilot cell is chosen, it should be retained, if possible, for the life of the battery to avoid introduction of irregularities into the record.

Proper Charging. Proper charging means charging at a rate to cause a minimum of heavy gassing and the least possible sedimentation. This requires very little makeup water.

Gassing results from electrolysis of water in the electrolyte by the charging current and is proportional to the excess of charging current over that required for conversion of the lead sulphate formed during discharge. For a given charging current, gassing increases as the lead sulphate decreases.

Full Charge. A cell is fully charged when, on equalizing charge, it is gassing and the specific gravity of the electrolyte, corrected for temperature and level, has stopped rising and remains constant during the last three hours of the equalizing charge.

If storage cells are overcharged, the service will be good, but their life will be shortened. After a battery is fully charged, continued charging at high rates is hard on the battery because violent gassing takes place which may break particles out of the positive plates. The coarse particles drop to the bottom, but the finer particles rise along with the gas bubbles and may result in a muddy red or brown color of the electrolyte. Cells tend to overheat on heavy overcharges and since high temperatures are destructive to the plates and separators, the temperature of the cells should not exceed 110 degrees Fahrenheit during such charging.

Momentary heavy charges are not harmful, but long sustained charges of high currents are damaging and should be reduced as soon as heavy gassing begins or when high temperatures are reached.

Constant Voltage Charging. The constant voltage method of charging is preferred for station control batteries because it results in longer battery life.

Following is the table of continuous floating voltages for various numbers and different Specific Gravity Rating of cells:

Specific Gravity Rating	Number of Cells	Normal Voltage Across Battery	Average Cell Voltage
Nominal 1.210 (1.200-1.220)	12	25.80	2.15
	24	51.60	2.15
	60	129.00	2.15
	120	258.00	2.15
Nominal 1.260 (1.250-1.270)	12	26.16	2.18
	24	52.32	2.18
	60	130.80	2.18
Nominal 1.275 (1.265-1.285)	6	13.20	2.20
	12	26.40	2.20
	24	52.80	2.20
	60	132.00	2.20

Equalizing Charging. The purpose of an equalizing charge is to insure that every plate in each cell is fully charged by a reasonable overcharge, that every cell gasses freely at equal rates, and that the specific gravity of all cells has stopped rising and leveled off near the top specific gravity reading for the battery before the equalizing charge is stopped.

A battery that is kept on continuous floating charge should be given an equalizing charge once each month, or after failure of the battery charger for any period of time, or when the specific gravity of the pilot cell is more than ten points (0.010) specific gravity below its full charge value.

The equalizing charge is given by raising the voltage across the battery for 24 hours.

Discharging. A battery may be discharged at any rate current it will deliver without any damage to the plates. The maximum permissible rate of discharge is limited only by the current-carrying capability of the terminals, connectors, and conductors, and not by the plates themselves. The ampere hours a battery will provide are greater for a long, low or intermittent rate than for a short, high rate of current.

Water Replacement. Distilled or approved water should be added often in small quantities to maintain the electrolyte level to the top level recommended by the manufacturer. The water should be added before or at the start of the equalizing charge to insure thorough mixing before specific gravity readings are taken.

Adjustment of Specific Gravity. Adjustment of specific gravity should never be necessary in a battery unless it has been flooded or acid has been lost. Adjustment of specific gravity by the addition of acid should never be undertaken until it has been definitely established that the gravity is incorrect.

Hydrometer Readings. The specific gravity of a cell is obtained by use of an hydrometer to determine the state of the charge of the cell. A scale of 1.100 to 1.300 is preferable for ease of reading and to cover the specific gravity range of all cells.

To take a reading, insert the nozzle of the hydrometer syringe into the cell, squeeze the bulb, and then slowly release it, drawing up just enough electrolyte from the cell to float the hydrometer freely. Holding the syringe vertically, the reading on the stem of the hydrometer at the surface of the liquid is the gravity reading of the electrolyte. After testing, always return the electrolyte to the cell from which it was taken.

Both temperature and level of electrolyte affect the specific gravity reading somewhat and it is therefore desirable to record the temperature. A gravity reading should not be taken immediately after adding water, otherwise the reading will be false. Allow a day or so for the water to mix with the electrolyte by gassing of the electrolyte resulting from charging or floating the battery.

The temperature correction for batteries rated 1.210 nominal specific gravity is minus 0.001 for each three degrees the temperature is below 77 degrees Fahrenheit and plus 0.001 for each three degrees the temperature is above 77 degrees Fahrenheit. For

1.260 and 1.275 nominal specific gravity batteries, this correction is 0.002 specific gravity for each five degrees beginning at 80 degrees Fahrenheit temperature.

Voltmeter Readings. Voltages taken when the battery or cell is open circuit do not give much information, except zero voltage may indicate an internal short circuit.

During discharge at any rate, the discharge should be stopped when the voltage drops to 1.75 volts per cell.

Temperature Characteristics. Performance of cells is greatly affected by their operating temperature. Discharge capacity is greatly reduced at lower temperatures. The local action or self-discharge rate is greatly increased at high-temperatures. Storage cells should not be exposed to the direct rays of sunlight, as such cells will operate hotter and deteriorate at a greater rate. The higher the specific gravity, the lower temperature at which the electrolyte will freeze and damage the cell.

Check-up: (2-6-4)

1. Why should storage batteries be charged from a d-c voltage source higher than the voltage of the battery? When connecting a battery charger to a battery, should the positive terminal of the battery be connected to the negative or positive of the charging circuit?
2. What is the chief use of storage batteries in power and substations and why are they used?
3. What harm can be done by excessive or overcharging and how can the normal charging rate be determined?
4. What is the voltage per cell of a fully-charged storage battery?
5. What is an equalizing charge?
6. What is the pilot cell?
7. Is the sediment which collects underneath the plates any cause for alarm?
8. Electrolyte loses some of its water by charging of the battery and some by evaporation. Is it necessary, therefore, to add new electrolyte?
9. Why should hydrometers and other lifting tools used in a battery room be made of rubber, glass, or be well protected with a rubber covering?
10. Of what use is a soda solution in a battery room?

DIRECT-CURRENT GENERATORS

A study of the lessons which follow would provide you with:

1. An understanding of the principles, construction, and types of d-c generators.

2. An appreciation of the importance of generators with regard to your work in the electrical field.

3. An understanding of new terms and symbols and their significance as they are used for the identification of fields and armatures and their exterior leads.

4. A knowledge of the main parts of the internal circuits of generators and of the functions of these parts.

Directions:

Study the information sheets and the required references. Keep the study-help questions following each topic of the information sheet.

Study-help questions:

1. Describe briefly the operating principle of the basic d-c generator.

2. What is an "armature"? What is a "commutator"? Why is it used?

3. What is meant by induced emf? What determines the strength of the induced emf in a generator?

4. What is: (a) a series generator? (b) a shunt generator? (c) a compound generator?

Lesson 2-6-5
THE D-C GENERATOR

Required reference:

Electricity One-Seven,

Additional reference:

Croft's American Electricians' Handbook,

Check-up: (2-6-5)

1. What serves an an automatic reversing switch on a d-c generator? What is its purpose, why is it necessary?

2. What is meant by the neutral plane in a d-c generator? What would happen if the brushes were not positioned in the neutral plane?

3. How is the generator ripple reduced in a d-c generator?

4. Will increasing the number of turns in the armature coils affect the amount of ripple in the output voltage of a d-c generator?

5. If a generator has eight commutator segments, how many separate armature coils does it have?

6. How can you control (increase or decrease) the voltage output of a d-c generator?

7. Does the number of armature coils affect the number of brushes required for a d-c generator?

8. Can alternating current be used as a field for a d-c generator? What type of current must be used?

9. What is excitation current? Explain the difference between separately excited d-c generators and self-excited generators.

10. Why does a series generator have poor voltage regulation?

11. Why are shunt generators said to be self-protective?

12. What type of d-c generator has its field connected in parallel with its armature? What type of generator has its field connected in series with its armature? What is the generator called that has both a winding connected in series and a second winding connected in parallel?

13. What is meant by the reference to "build-up" of a d-c generator? Is this necessary in separately excited generators?

14. In a compound generator, do the magnetic fields of the two windings aid or oppose each other?

15. Which type of generator will supply the more stable voltage for varying load conditions: series-, shunt-, or compound-wound generators?

Lesson 2-6-6
D-C GENERATOR CONSTRUCTION

Required reference:

Electricity One-Seven,

Additional reference:

Croft's American Electricians' Handbook,

Check-up: (2-6-6)

1. When a generator has a large number of poles, is the total number odd or even? How are the field coils mounted (do they rotate or are they fixed)?
2. What is armature reaction? What causes it? Why can it be troublesome?
3. What are interpoles? What reaction do they correct for?
4. What are compensating windings and what is their purpose?
5. Name the two types of windings used on an armature.
6. Why is the armature core and the field-winding core of a generator laminated? What material is generally used for these cores?
7. What are the pole pieces? What is their function? Why are pole pieces shaped to fit the curvature of the armature?
8. What are commutator bars made of? Must the commutator and brushes of a generator be lubricated? Why?
9. What characteristic has carbon that makes a favorable material for use as brushes on d-c machines?
10. What is the most common method of dissipating the heat generated in a d-c generator?

A-C GENERATORS

Your study of the lessons which follow will help you obtain:

1. An understanding of the principles involved in the production of electric power by means of a-c generators or "alternators".

2. A working knowledge of alternator construction and design.

Directions:

1. Study the required reference.

2. Read any additional references that may be assigned by your instructor.

3. Write out and hand in to your instructor the answers to all the check-up questions.

Lesson 2-6-7
THE A-C GENERATOR

Required reference:

Electricity One-Seven,

Additional reference:

Croft's American Electricians' Handbook,

Check-up: (2-6-7)

1. Name two advantages of the rotating field type alternators as compared to the rotating armature type a-c generators.

2. In an a-c generator, what is the rotor? The stator? What part produces the magnetic field in most alternators?

3. Are slip rings required on a stationary-armature generator? What is the function of the slip rings (do they carry a-c or d-c current)? Why are brushes used?

4. How does the speed of rotation affect the frequency of the voltage generated? What is the relationship of frequency, number of pairs of poles, and the rpm in an alternator?

5. What advantages do a-c generators have over d-c generators?

6. Why do a-c generators have poorer regulation than d-c generators?

7. What are motor-generators used for?

8. Why are a-c generators normally not rated in watts or kilowatts?

9. An a-c generator has a rating of 20 kilovolt-amperes and an output of 2 kilovolts. What is the maximum current it can safely deliver?

10. What is the function of a dynamotor? What is a converter?

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Lesson 2-6-8
A-C GENERATORS

Additional information:

The voltage of any generator depends on the field strength and the speed of the rotor. If a generator must operate at a constant speed in order to maintain a fixed frequency, the output voltage of the generator is dependent on the d-c field (excitation current). If a generator is supplying power to an isolated load, increasing the field current will raise the output voltage of the generator and similarly by reducing the d-c field current the output voltage will be lowered.

In modern power systems it is common practice to operate all the generators in parallel, as all the generators in any power system are tied together through transformers, buses, and/or power lines, and so increasing or decreasing the d-c field current has a much smaller effect on the output voltage. The generator is connected to the system and one generator by itself feeding into a large system containing many other generators can effect the system voltage only slightly. The effect of increasing the field current is subsequently noted to effect the reactive power flow (kilovar or megavar). Over excitation of the generator will cause reactive power to flow from the generator to the system, while under excitation will cause the generator to take in var, that is reactive power will flow from the system back to the generator.

The kilowatt load of the generator is determined by the input to the prime mover. The input to the steam turbines, water wheels, diesel engines, or whatever, is controlled by sensitive governors and is held to a fixed value by means of the governor control. The setting of this governor is what determines the true power output in kilowatts of machines operating in parallel and it will not change appreciably, even though the field excitation is changed. The internal operating conditions caused by armature reactance and armature reaction adjust themselves so that the output voltage and output power of the individual generators in parallel remain relatively constant with changes in field excitation.

Before a-c generators can be paralleled onto the system, or paralled with any other a-c generator, several conditions must be fulfilled. The output voltages must be equal to the system voltage, the frequency must be the same for the incoming generator as for the running generators (the system frequency - 60 hertz in the United States), and their output voltages must be in phase. For three-phase generators, the phase sequence must also be the same. When all these conditions are met, the generator is said to be in synchronism and the actual process of paralleling generators is called synchronizing. A synchroscope is normally used to indicate very accurately any difference in frequency and phase angle between the voltage of the incoming generator and the running generator or generators. Most modern generating plants utilize an automatic synchronizer which will automatically close the generator onto the system when all of the conditions for synchronizing are met. Closing the generator breaker when the alternator is out of phase with the system can result in damage to the generator and is a severe shock to the complete system as tremendous fault currents are generated.

Check-up: (2-6-8)

1. Most three-phase alternators used in modern power generating stations are wye connected. The output terminals are commonly labeled T1, T2, T3. The sequence of the voltages for correct rotation is phase 1, 2, 3. If the sequence of voltages was found to be 1, 3, 2, would they still differ in phase by 120 degrees?

2. The output voltage of a three-phase, wye-connected generator is 13.8 kv. The generator is delivering 25 megawatts and 10 megavars to the power system. What amount of amperes would you expect to find in each phase (stator coil) of the generator? Assume a balance load.

3. Assume we have two alternators operating in parallel and it is desirable that the load should be shared between them. With d-c generators, the proper division of load between machines is obtained by changing the field excitation of the two generators until the load is shared between them. How are a-c generators adjusted so as to share the load?

4. A three-phase, wye-connected generator is rated for 24 kv and 1,200 amperes. Determine the kva rating of the generator.

5. If the generator in question 4 is delivering rated current to a load with 80 percent lag power factor, what is the megawatt output of the generator?

6. Explain what happens when an attempt is made to shift the kw load between alternators by changing the field excitation. Assume the governor control to the two prime movers is not changed.

7. A three-phase, delta-connected generator is rated at 10,000 kva, 11,000 volts, and 60 hertz. What is the full-load line current at unity power-factor?

8. In question 7 the generator efficiency is 86 percent. What must the horsepower input from the prime mover to the generator be if the generator is generating at full rating?

9. List four separate conditions that must be met before an alternator can be synchronized to parallel with another a-c generator.

10. A three-phase, wye-connected generator is rated at 50,000 kva and 13.8 kv. What is the voltage rating of each of the three windings? When 1,400 amps of load current flows in each phase winding, how much load current will flow in the lines, out to the load?

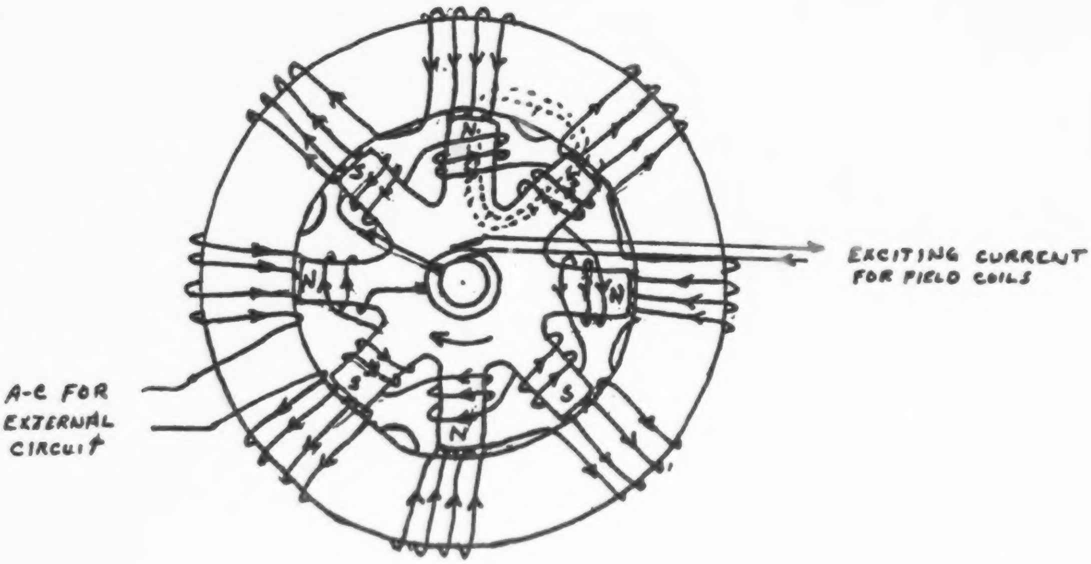
N
S
S
N
N
S
S
N
EXCITING CURRENT FOR FIELD COILS
A-C FOR EXTERNAL CIRCUIT

DIAGRAM OF A SINGLE PHASE
ALTERNATOR
WITH A REVOLVING FIELD

ELECTRICAL THEORY

UNIT VII

ELECTRIC MOTORS

This unit contains the following lessons:

D-C MOTORS

Lesson 2-7-1: D-C Motors
Lesson 2-7-2: Starters and Controllers

A-C MOTORS

Lesson 2-7-3: A-C Motors
Lesson 2-7-4: Check-up

D-C MOTORS

A study of the lessons which follow will help you obtain:

1. An understanding of the principles involved in obtaining motion from electricity.
2. A working knowledge of the various types of d-c motors and an understanding of why certain types are best for certain applications.
3. A knowledge of how motors are constructed.
4. A better understanding of counter emf.

Directions:

1. Study the references thoroughly.
2. Familiarize yourself with all new words, terms, and definitions.
3. Write out and hand in to your instructor the answers to all the check-up questions.

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Lesson 2-7-1
D-C MOTORS

Required references:

Electricity One-Seven,

Croft's American Electricians' Handbook,

Check-up: (2-7-1)

1. What important role does the commutator play in the operation of the d-c motor?

2. What are the effects of "armature reaction" in a motor? In what direction is the neutral plane shifted by armature reaction?

3. What is the relationship between the number of commutator segments and armature windings?

4. What characteristic has a shunt-wound motor that makes it suitable for driving certain types of machinery?

5. How may the speed of a shunt-wound motor be varied? What controls the speed of a series-wound motor?

6. To what types of load is a series-wound motor especially adapted?

7. What is a compound-wound motor and what advantages does it have over both shunt- and series-wound?

8. What is "counter emf"? Why is a resistor necessary for starting a d-c motor?

9. Why will a motor speed up when the strength of the field decreases?

10. How do you reverse the direction of rotation on a d-c motor?

STARTERS AND CONTROLLERS

You are to acquire from the lessons which follow:

1. A knowledge of the various d-c motor starters and controllers, as well as the principles involved.

2. A knowledge of the various control devices used to start, stop, and protect d-c motors and equipment.

3. An understanding of the physical makeup of motor controls which will be valuable in troubleshooting and maintaining motors and their associated equipment.

Directions:

1. Observe and help install motors whenever possible. Ask questions about the various troubleshooting techniques and maintenance procedures. Keep this data in your notebook.

2. Study the required reference.

3. Read about d-c motors and controllers in other reference books and manufacturers' catalogs and pamphlets.

4. Write out and hand in to your instructor the answers to all the check-up questions.

Lesson 2-7-2
STARTERS AND CONTROLLERS

Required reference:

Electricity One-Seven,

Additional reference:

Croft's American Electricians' Handbook,

Check-up: (2-7-2)

1. Why do all d-c motors require some type of starter or controller?

2. How are manual starters classified?

3. Explain the difference between a motor controller and a starter.

4. What kinds of motors are controllers normally used with?

5. How may the speed of a compound-wound motor be varied or controlled?

6. What is meant by "dynamic braking" and how is it accomplished?

7. When are drum controllers most useful?

8. With the above- and below-normal speed controller, when is the armature resistance changed? The field resistance?

9. What kind of protection do you have with an automatic controller?

10. What extra motor control does a drum controller give?

A-C MOTORS

Your study of the lesson which follows will help you obtain:

1. An understanding of the principles involved in the operation of a-c motors.

2. A knowledge of the various types of a-c motors.

3. A knowledge of how synchronous motors are used as a rotating capacitor.

Directions:

1. Observe and help install motors whenever possible. Ask questions where you work.

2. Study the required reference.

3. Read about a-c motors in other reference books and manufacturers' catalogs and pamphlets.

4. Write out and hand in to your instructor the answers to all the check-up questions.

Lesson 2-7-3
A-C MOTORS

Required references:

Electricity One-Seven,

Croft's American Electricians' Handbook,

Check-up: (2-7-3)

1. What are two general types of alternating-current motors?
2. Are a-c motors more or less troublesome to operate than d-c motors?
3. What specific types of induction motors are there?
4. A three-phase motor operates on what principle?
5. Just what is meant by motor "slip"?
6. What is a "squirrel-cage" winding?
7. What other types of winding are used on rotors of induction motors?
8. How may the speed of an induction motor be controlled or varied?
9. Describe the construction of a synchronous motor.
10. Why is it that a synchronous motor cannot be started by applying three-phase a-c to the starter?
11. On what kind of loads are synchronous motors used?
12. How can synchronous motors be designed to be self starting?
13. What type of current is used to magnetize the rotors of large synchronous motors?
14. How can the use of synchronous motors improve a plant's power factor?

Lesson 2-7-4
Check-Up

Required references:

Electricity One-Seven,

Croft's American Electricians' Handbook,

Check-up: (2-7-4)

1. On a 60-cycle system what will be the speed in rpm of a 12-pole motor?
2. How are motors wound so they may be used on more than one service voltage (for example 240 or 480 volt)?
3. How may the rotation of a three-phase induction motor be changed?
4. Will a three-phase series motor continue to run at normal speed if one fuse blows?
5. What is meant by the term "torque"?
6. What is meant by a single-phase series motor and where are they used?
7. What is a repulsion motor and in what way is it similar to a d-c motor?
8. Is there any electrical connection between rotor and field of an induction motor?
9. What determines the speed of an induction motor?
10. What will be the speed of a single phase two-pole motor on a 60-cycle circuit?
11. Describe the construction of a repulsion-induction motor rotor.
12. What is a synchronous condenser? For what is it used?
13. Name two ways in which capacitors are used on single-phase induction motors.
14. State the most common use for synchros or "Selsyn" motors.
15. What effect does low voltage have on the operation of a-c motors?

ELECTRICAL THEORY

UNIT VIII

ELECTRICAL DRAWINGS AND DIAGRAMS

This unit contains the following lessons:

Lesson 2-8-1: Electrical Print Reading
Lesson 2-8-2: Electrical Print Reading - Point to Point
Lesson 2-8-3: Lineless Wiring Diagrams
Lesson 2-8-4: Diagrams for Capacitor Bank Control
Lesson 2-8-5: Print Reading - Test Your Knowledge

ELECTRICAL PRINT READING

In order to read a blueprint or diagram, one must first become familiar with the meaning of symbols, lines, and the other abbreviations employed by the engineers and draftsmen who design the substations and power plants. There are many types of blueprints necessary for the construction of a power station. Many of the drawings are primarily mechanical drawings that represent the physical arrangement and the views of specific electrical apparatus or their parts with their shapes and dimensions. These drawings usually give all the plan views, the elevations, sections, and details necessary to erect the structures or equipment.

These mechanical-type drawings are not particularly hard to read, as they usually indicate how the structures, or equipment, will actually look when the construction is completed. Dimensions and distances are always tied down with some fixed object, foundation, or ground point. Dimensions are almost always shown by lines having arrowheads at both ends. The dimension line is usually broken to permit the insertion of the dimension.

The arrangement of views on mechanical drawings is important. The system commonly used by most draftsmen is the third angle projection. The plan, or top view, is at the top of the sheet; the front (or A-A) elevation projects directly beneath it, and an end (or B-B) elevation is projected to the right of the front elevation. The pairs of arrows, identified by the same letters, indicate the direction in which the object in the plan view is viewed in order to obtain the elevation. Drawings of this type are most often used when showing the electrical arrangement of the equipment in the substation.

When a complicated arrangement of a structure cannot be completely shown with only three views, additional elevations may be shown. In cases where this is so, a section plan is most often added to the top plan view with the additional views clearly marked to show the direction the elevation is taken.

Drawings cannot always be made that will show all the information necessary to those who will use the prints. This makes it normal to include on the drawings notes, or data, worded as briefly as possible. Common practice of most draftsmen and engineers is to place these on the right-hand side of the drawing, some distance above the title, which is usually located in the lower right-hand corner. The title will include such things as the scale used, the design engineer, date completed, number of the drawing, and any revisions, etc., and the name of the station or project.

In addition to the notes, other drawings that pretain to installation are normally listed, such as the foundation plan, the grounding and conduit plans, the wiring diagrams, if any, and any other drawings that may be useful to any who will use these prints.

When construction begins on a power plant or a substation it is necessary to have a set of drawings that show not only the location, architectural and mechancal drawings but also a set of electrical drawings. The electrical drawings include the electrical arrangement of the equipment, one-line and three-line schematic diagrams, wiring diagrams, and a grounding and conduit layout print, a conduit-and-cable list, and a list of material.

The list of material is not, in fact, an electrical diagram, but is a bill of material and includes much important information. There is no particular standard, as each company has its own way of listing the material used on a job. In most instances, the bill of material is divided into several columns. In the first column will appear the item number corresponding to the item number applied to the equipment. The second column lists the quantity of each item. In the third column will likely be a complete description of the item to be used. The fourth column will list where the item is to be procured; from store stock, from salvage, or if the article is to be purchased from a specific manufacturer. A fifth column may be provided for any miscellaneous information that is felt necessary to pass along, such as special modifications that might be needed.

The list of material is of special interest to a number of people. It is important to the purchasing department who must purchase the exact items listed, and it is important to the people involved with the construction of the station because it tells the workers exactly where the different parts will be used.

When an electrical design engineer or draftsperson begins to list the materials that are shown on the drawings, the parts and equipment do not have item numbers. The draftsperson assigns item numbers as the material list is formed. Usually the draftsperson will start with the major equipment, such as the transformers, oil circuit breakers, and switches. Then they count all the various insulators, bus fittings, relays, and devices that are needed. As each piece of material or equipment is entered on the material list, it is assigned an item number. This number is also recorded on the drawing next to each piece of material or equipment. The item number is usually applied to the piece of equipment in only one view.

For a large job, a conduit and cable-pulling schedule is often included. The draftsperson scales the lengths from the drawings to get the quantity that is needed. Of course, one must make allowances for errors when determining the length of the conduit, as well as the length of the cable, as the lengths are intended to be approximate. Conduits and cables are numbered and listed, giving the size of the conduit and the number of cables or wires to be pulled into which conduits, along with their length and the point of their origin and destination. The type of cable, size and number of conductors is normally noted, also for what purpose will the wires be used, control-power-lighting-etc.

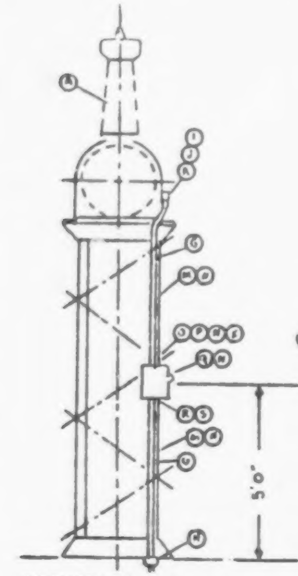
Electrical wiring in residences is for the most part intended for lighting circuits, household appliances and devices for heating. Although most power stations do have some wiring installed for this purpose, the lion's share of the wiring done in a substation is to enable the substation to receive electrical energy at high voltage and transform it to a lower voltage suitable for distribution. The electric-power substation constitutes a very important part of any electric power system. Most modern substations for high voltages are built outdoors, although distribution substations in metropolitan areas can be found within the buildings of commercial customers.

A modern substation will normally contain in addition to the power transformers, circuit breakers, voltage regulators, disconnect switches, lightning arrestors, protective devices, instrument transformers, and meters, to list only a few of the devices. The substation has many parts and complicated connections, and each device has an important role in the proper functioning of the substation. Without electrical diagrams, it would be near impossible to design, build, operate, or maintain a substation.

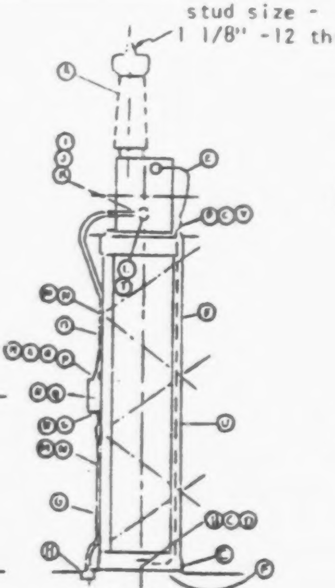
Circuits for substation lighting receptacles and heating are provided and are usually shown on a lighting plan or substation layout. The source of power is usually a distribution transformer, designated "station service", of sufficient size and rating to provide a three-wire single-phase 120-240 volt feed to the bus in the a-c supply box, or distribution center as it is commonly called. Circuits feeding loads out of the distribution center are called branch circuits and each circuit is fused or protected with a circuit breaker.

Electrical-Arrangement-Drawings are used to show the physical arrangement of the structure, buses, and electrical equipment. The complete set of drawings would consist of a plan view and various elevation views as are necessary to convey to the electrical construction workers all the information necessary to position and install the electrical equipment shown on such drawings. The elevation views obtain their label from the plan view which will indicate where the elevation is taken (i.e., A-A, B-B, and C-C). Electrical arrangement drawings are made to scale and it is customary where a plan view is shown to make the direction north. The electrical arrangement is not used to show where or how to erect the structure. Steel erection diagrams and foundation details are shown on separate drawings.

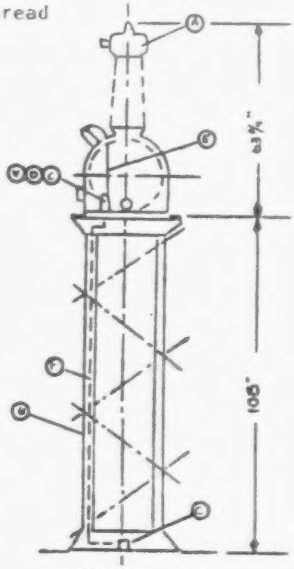
One important point to emphasize is that all major equipment and steelwork is grounded and every point where a ground wire enters the station ground grid, the connection is indicated.



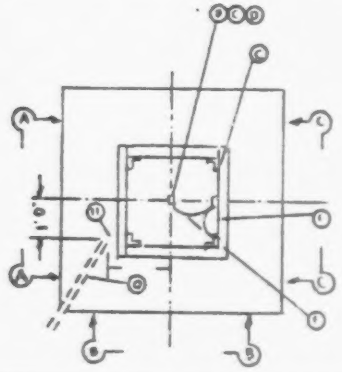
ELEVATION A·A


stud size -
1 1/8" -12 thread

ELEVATION B·B

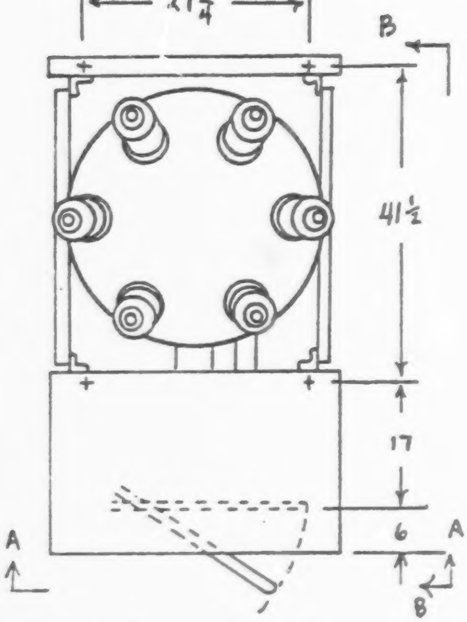


ELEVATION C·C



CONST NOTE

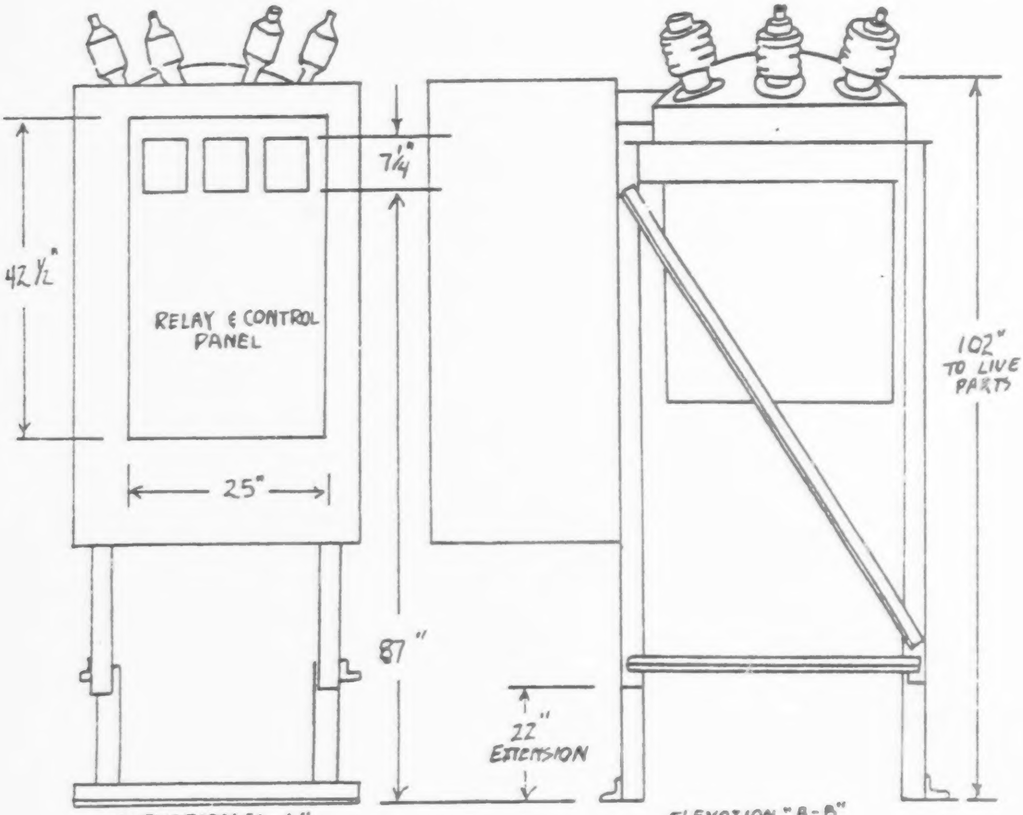
Prepare the surface behind ground clamps by applying a coating of galvaloy or equal to ungalvanized steel members and to locations on steel members where the galvanizing has been removed. Then wash with alcohol.


27 3/4
B
41 1/2
17
6
A
A
B

The electrical construction drawings are drawn to scale and show the physical arrangement of the electrical equipment. They indicate how the structures or equipment will look when erected.

Shown here is the outline for a 13 KV oil circuit breaker. The system used is the third-angle projection, with the arrangement of views.

The plan, or top view, is at the top of the sheet; the front elevation, or A-A elevation, projects directly beneath it; and an end elevation, or B-B elevation is projected to the right of the front elevation.


7 1/4"
42 1/2"
RELAY & CONTROL PANEL
25"
87"
22" EXTENSION
102" TO LIVE PARTS

ELEVATION "A-A"

ELEVATION "B-B"

LIST OF MATERIALS

ITEM	DESCRIPTION	STOCK NO.	CAT. NO.
A	SPW 61 POT. TRANSFOMER	3-82-460	
B	GROUND PAD 250 MCM	1-16-545	
C	CLAMP GROUND, 2 BOLT WITH BOLTS, LOCKWASHERS & NUTS	1-16-540	
D	MACHINE BOLTS 1/2 X 2" EVERDUR	5-16-643	
E	NO. 2 BARE, SOLID COPPER WIRE	6-07-245	
F	250 MCM BARE COPPER GND WIRE SOFT DRAWN	6-07-360	
G	CONDUIT, 3/4" RIGID STEEL GALV.	4-04-013	
H	COUPLING, 3/4" CONDUIT	4-04-213	
I	COUPLING, 3/4" ERICKSON	4-04-313	
J	3/4" X 2" CONDUIT NIPPLE	5-29-482	
K	REDUCER, CONDUIT 1" to 3/4"	PROCURE	
L	ELL, STREET, 90° 3/4" GALV.	5-29-234	
M	STRAP, 1 HOLE 3/4" MALLEABLE IRON	5-29-823	
N	MACHINE SCREWS 1/4" X 20 X 1" WITH NUTS	5-38-540 5-26-425	
O	GASKET, CONDUIT HUB	4-04-435	
P	HUB, 3/4" REMOVABLE	4-04-453	
Q	FUSE BOX TYPE 1	4-02-054	
R	LOCK NUT, 3/4" CONDUIT	4-04-513	
S	BUSHING, 3/4" CONDUIT	4-04-113	
T	SCREEN, WIRE VENT		
U	STRAP FOR 250 MCM STRD. COPPER	4-24-755	
V	TERMINAL LUG COPPER, 1 HOLE #4 TO 4/0	1-54-810	
W	MACHINE BOLT 5/16" X 1" EVERDUR	5-16-600	
X	NUT 5/16 EVERDUR	5-26-451	

Many engineers prepare and issue a plan view of the grounding system and conduits. The ground grid or grounding system is commonly made up from copper wire buried beneath the ground. The best practice is to use bare stranded copper cable. The size of the wire will be indicated on the drawing - #4/0 str. or 250 mcm, or whatever size has been specified. The grounding cable will be shown in its approximate location and according to company standards, as will the seven-foot long 3/4-inch ground rods. The fence must be grounded at least every so many feet, depending upon company policy. Equipment and structures must be grounded according to certain standards. A great deal of time, effort, and expense is necessary to insure a very low resistance ground grid in an effort to hold the ground rise potential to safe levels.

The conduit plan of the substation is customarily shown together with the ground grid. The purpose is to show the two ends of the conduits, any pull boxes, or vaults, and the approximate route of the conduits. If the length of a cable run is desired, it should be possible to scale from the plan, and by allowing enough length at each end for "makeup", determine the approximate length.

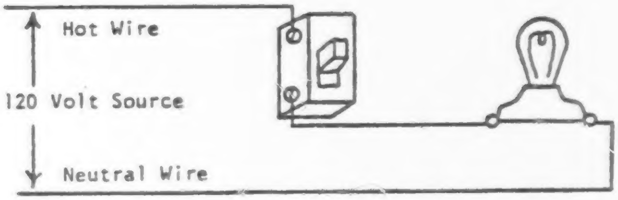
WIRING DIAGRAMS

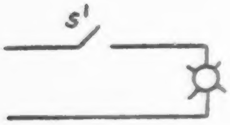
Wiring diagrams are drawings that are intended to show, in diagrammatic form, electrical connections. They are never drawn to scale, but only show the electrical association of the different electrical equipments. In diagram work, symbols are used extensively to represent the various pieces of electrical apparatus, and these symbols are connected by lines indicating the wires that complete the electrical circuits.

Many students have indicated to me that the mechanical drawings we have discussed in the previous pages are relatively easy to understand, but that wiring diagrams are something else. We will therefore devote most of our attention to mastering this type of drawing. We will start very basic and progress from there.

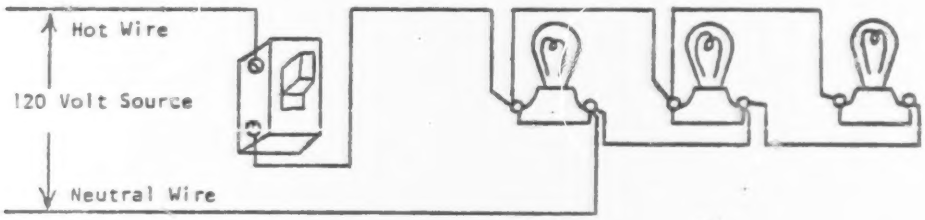
Every electric circuit can be considered to consist of two wires, if you wish: one wire carrying the current to the load, and the other wire returning the current to the source. If we consider a very simple circuit, such as a lamp controlled by a switch, it may help you to understand better if you will imagine that each wire is hollow, like a waterpipe - switches are shutoff valves, every lamp, relay, or appliance must have water (an electric current) flowing through it to operate.

Water (current) must flow in at one wire at the point marked "source", through the wire, switch, etc., through the lamp or appliance and back to the source which supplies the pressure (voltage). You have already learned that current cannot flow unless there is a complete circuit and unless this complete circuit can be traced, the lamp or device will not operate.

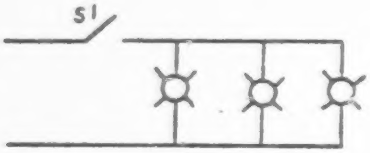

Hot Wire
120 Volt Source
Neutral Wire



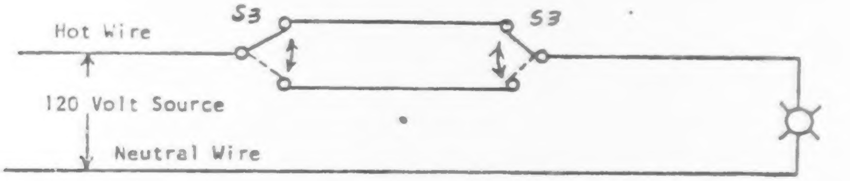
In actual practice, you may have several lamps or devices controlled by a single switch.


Hot Wire
120 Volt Source
Neutral Wire

Note that if one lamp burns out the others are not affected.



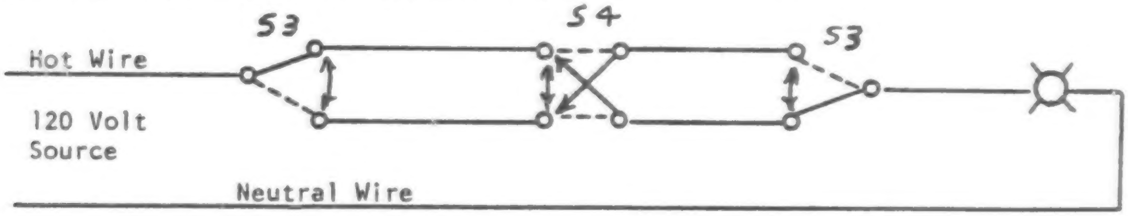
It is often desirable to control lamps or devices from two points, that is, two different locations. This is very simply accomplished by using switches known as "three-way" switches. If we assume that both switches are up, the light will be on because there is a complete circuit from the source to the lamp and return via the neutral wire.


S3
S3
Hot Wire
120 Volt Source
Neutral Wire

Throw one switch into the "down position" (dotted line) and the light will go out because the circuit has been broken. If you move to the other switch location and place it in the "down" position (dotted line), the light will be turned on again. In otherwords, the light can be turned on and off from either of the two switches. The two wires that are connected to run between the two switches are commonly referred to as travelers.

In using three-way switches, note that on one end of each switch there are two places to connect wires. Two wires are run from these terminals to the two terminals on the other switch. These two wires are the travelers.

Sometimes it is found necessary to turn a light on or off from more than two points. In this case, use two three-way switches for the first two locations, and a four-way switch at each additional point or location. Four-way switches have four terminals in which to connect wires.



The National Electric Code provides that all wiring systems carrying alternating current must be grounded; it is seldom that any kind of system is not grounded. In switching circuits, the hot wire is the one broken by the switch. The neutral or white wire is grounded and always runs from the grounded, unfused side in circuit or fuse cabinet, direct to sockets, receptacles or other devices, without being interrupted by a switch. On most circuit cabinets, receptacles, sockets, etc., you will find one terminal natural brass color and one a dull "silver" or "tin" color. The white wire always fastens to this white "silver" color terminal.

Connection diagrams, or wiring diagrams, show the connections to an installation or a specific piece of equipment. It can be thought of as a diagram used to interconnect devices of a switchgear equipment assembly. It may or may not show internal connections or devices.

A wiring diagram is more pictorial in nature than schematics and, in general, devices are shown in a form representative of the physical arrangement of the terminals to which connections are made. Wiring diagrams of switchboard panels are always shown as a back view of the panel because the wires are on the back of the panel. If you are working on the wiring you will be facing the back of the panel.

The wiring or connection diagram is of limited value after the equipment is in and working. Its chief value, of course, is for making connections on the original installation, or when it becomes necessary to modify the connections to the equipment in some way.

As stated previously, wiring diagrams are not drawn to scale and the equipment is shown in its relative position only. The space between the equipment on wiring diagrams is often governed by the number of wires that must be shown there. There are a number of conventions that promote uniformity, but there are at least three distinct types of wiring diagrams.

The first type of diagram used only on the simpler pieces of equipment will show all wires by individual lines. In the second type of diagram the line from each device terminal is given an identification code number. The line is then combined with other wires so that a group of wires is represented by a single line. At the other end, the terminals are given similar code numbers to indicate to what each wire connects. Since fewer wires are shown in a wiring diagram of this type than are shown in type one, the diagram is not so crowded and tracing is made easier.

A common method of identifying each wire is to provide a break in the line that connects to the terminal, the identification code number is then written in the breaks in the lines. Every conductor shown entering a group is identified by the same distinguishing number, letter, or sign, as used to identify it at the opposite end of the group or terminal.

A third type of wiring diagram being used by engineering firms today does not show any lines to represent wires and therefore this type is referred to as "lineless diagrams". Each device on a piece of switchgear, relay, or control panel, is assigned an arbitrary letter, or set of letters and/or numbers. Such code letters are also assigned to each terminal block, fuse block, resistor, relay, or any other accessory device to which wires are attached, and all terminals on the devices must be numbered. Every physical wire has to be coded for identification by a number, or by a letter and a number. We call these numbers "wire numbers". The wires are not shown as lines, but are listed in a chart on the diagram. A schematic diagram is also prepared and the same coding must appear on both diagrams. If you must trace the wiring on a lineless diagram, it is most easily accomplished by referring to the schematic diagram.

The connection chart, sometimes called "wire table", always has a minimum of three vertical columns. The first vertical list is the "wire numbers" or "wire code". The second and third vertical columns are under the headings of "from" and "to" and simply distinguish one end of a wire from the other. Sometimes a fourth "wire size" column is included which is self-explanatory (i.e., it indicates the AWG size of each individual wire).

Electrical schematics are most often shown on a separate drawing. They are drawn in the straight line form and the coils and contacts of relays or different pieces of equipment are sometimes entirely disassociated. A switch and a light bulb, for example, indicated next to each other in the schematic diagram may actually be located in different rooms.

Schematic diagrams use mostly accepted standard symbols to represent electrical devices. They are not drawn to scale and do not show the shape of devices. Straight lines joining the symbols representing electrical equipment indicate the equipment is connected. Whenever applicable, devices are designated by standard ASA function numbers and suffix letters. Included in the back of this text is a list of ASA device numbers and functions.

A wiring diagram usually indicates the actual layout of wires on panels or between devices. A schematic diagram may use the same symbols, but it is in effect a shorthand explanation of the manner in which a group of electrical devices operate. Control schematics are drawn with all the equipment shown in the de-energized position unless otherwise stated. Normally, open switches are shown with their contacts open, and closed switches are drawn closed.

The wires between symbols are drawn either horizontally or vertically, but this does not mean that the actual wire which physically connects the two devices must be horizontal or vertical. The persons who will use the diagram are presumed to be reasonably familiar with the operation of the devices. The same symbol may be used to represent different devices. For example, a circle generally means a relay, motor, lamp, meter, or any device that might consume electric current. A letter or device number in the circle usually makes the meaning clear to the reader.

A schematic diagram is very valuable in troubleshooting. They indicate primarily connections of devices in an electrical system. The circuit must be complete to operate correctly. Schematic diagrams are used to check the completeness of the circuit. The wiring diagram of the same circuit will show you the location of the devices so that you can find which part of the circuit is faulty.

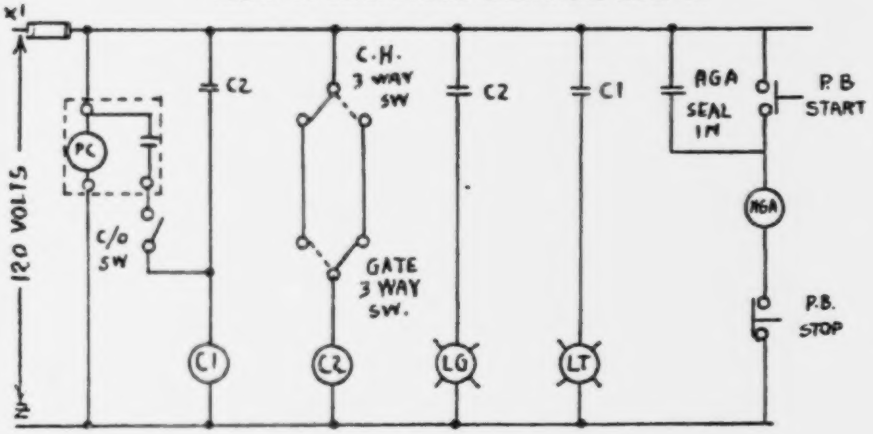
There are several types of schematics commonly used. Basically, they may be classified as a "one line schematic", a "three line schematic", and the "control schematic". Regardless of the actual number of wires between components of a circuit, the one line schematic uses a single line between symbols. The one-line diagram is very useful in showing the overall scheme for a generating or substation. If three lines are drawn to show all three phase wires, the diagram would be known as a three-line diagram. Three-line schematic diagrams are most useful in showing the connections of power transformers, CT's, PT's, instruments and relays. Control schematics, as previously mentioned, are drawn to indicate electrically how the electrical device, or group of devices, operate.

On pages 185 , 186 , 187 , and 189 , are some wiring diagrams that can be easily assembled for classroom exercises. Students who are just beginning will benefit most if they are able to wire up each exercise and make the models operate, analyzing the operation from the schematic diagram. Your instructor may be able to provide most of the relays, pushbuttons, switches, lamps, sockets, and short scraps of wire necessary. It is suggested that the equipment be mounted on a plywood stand; however, all these devices will operate just as well if left free standing. To expedite the connections, flexible wire equipped with alligator test clips is found to be invaluable.

The relays used for these models are General Electric type HGA 120 volt, Westinghouse type MG-6 120 volt (with an electric reset), a-c relays. Several Alan Bradly pushbutton combinations, as commonly used on motor control were used, as well as an assortment of 10-watt, 120-volt light bulbs and sockets. Switches can be of the type normally used in residential or commercial lighting (one single-pole-single-throw, two three-way, and one four-way).

WORKING MODEL FOR SUBSTATION LIGHTING
TO BE ASSEMBLED IN THE CLASSROOM

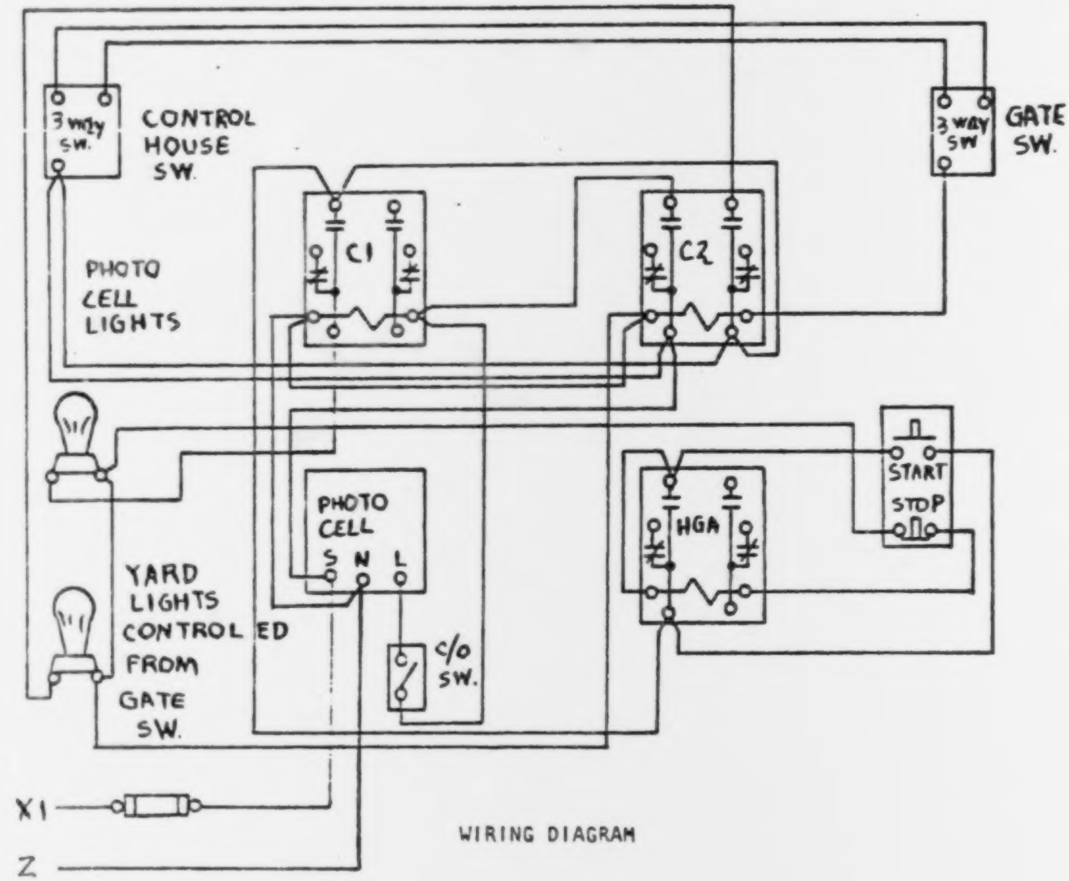
ALSO INCLUDES PUSHBUTTON STATION AND HGA
RELAY TO DEMONSTRATE ELECTRICAL SEAL IN


X1
120 VOLTS
N
PC
c/o SW
C2
C.H. 3 WAY SW
GATE 3 WAY SW.
C2
C1
HGA SEAL IN
P.B START
HGA
P.B. STOP
C1
C2
LG
LT

L E G E N D

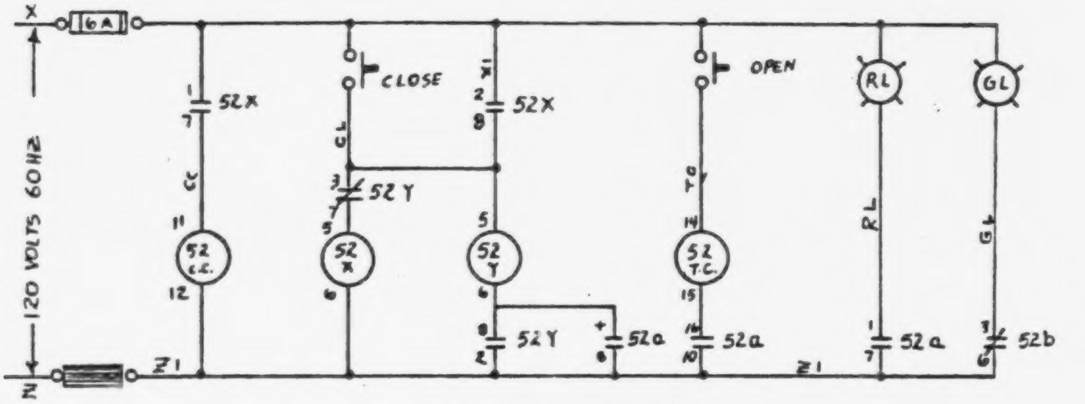
PC = Photocell
c/o SW = Cutout Switch
C1 = Photocell Contactor (HGA)
C2 = Gate & Control House Contactor (HGA)
LG = Gate Switch Yard Lights
LT = Photocell Yard Lights

CONTROL SCHEMATIC

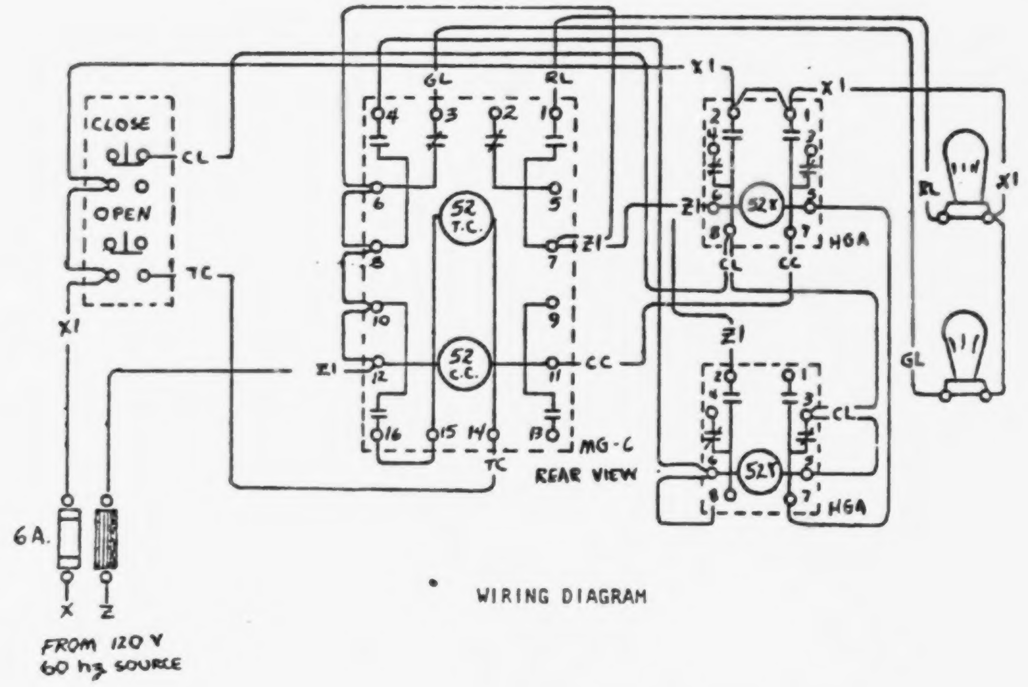

3 way SW.
CONTROL HOUSE SW.
3 WAY SW
GATE SW.
C1
C2
PHOTO CELL LIGHTS
START
STOP
HGA
PHOTO CELL
S N L
c/o SW.
YARD LIGHTS CONTROLED FROM GATE SW.
X1
Z

WIRING DIAGRAM

WORKING MODEL FOR CLASSROOM DEMONSTRATION OF TYPICAL 52X - 52Y RELAYS WHICH PROVIDE ANTI-PUMP FEATURE UTILIZED IN POWER CIRCUIT BREAKERS USING MG-6 RELAY WITH ELECTRIC RESET FOR BREAKER MECHANISM SIMULATOR

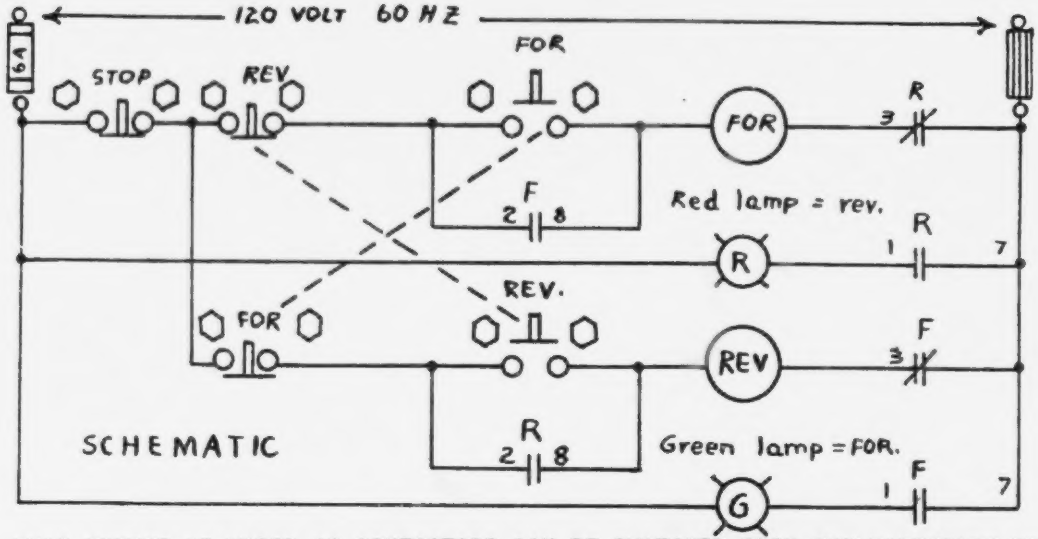

X
6A
120 VOLTS 60 HZ
Z
Z1
52X
52 C.C.
CLOSE
GL
52Y
52 X
X1
52X
52 Y
52Y
52a
OPEN
52 T.C.
52a
RL
GL
RL
52a
GL
52b

SCHEMATIC DIAGRAM


CLOSE
CL
OPEN
TC
X1
GL
RL
52 T.C.
52 C.C.
Z1
CC
MG-6
REAR VIEW
TC
X1
52X
HGA
CL
CC
Z1
52Y
HGA
RL
X1
GL
6A.
X
Z
FROM 120 V
60 hz SOURCE

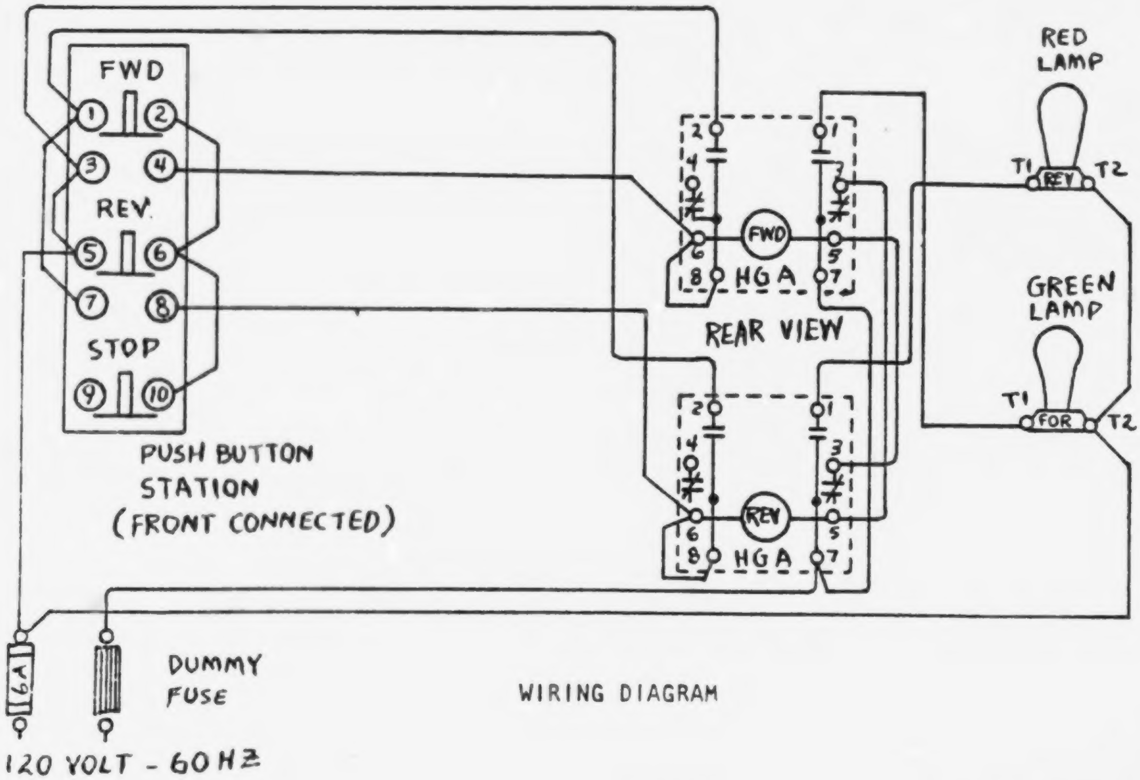
WIRING DIAGRAM

A SIMPLE WORKING MODEL FOR CLASSROOM TO DEMONSTRATE FORWARD REVERSE STOP MOTOR CONTROL INTERLOCKED THROUGH PUSHBUTTONS


120 VOLT 60 HZ
6A
STOP
REV
FOR
FOR
R
3
F
2
8
Red lamp = rev.
R
R
1
7
REV.
FOR
REV
F
3
R
2
8
SCHEMATIC
Green lamp = FOR.
G
F
1
7

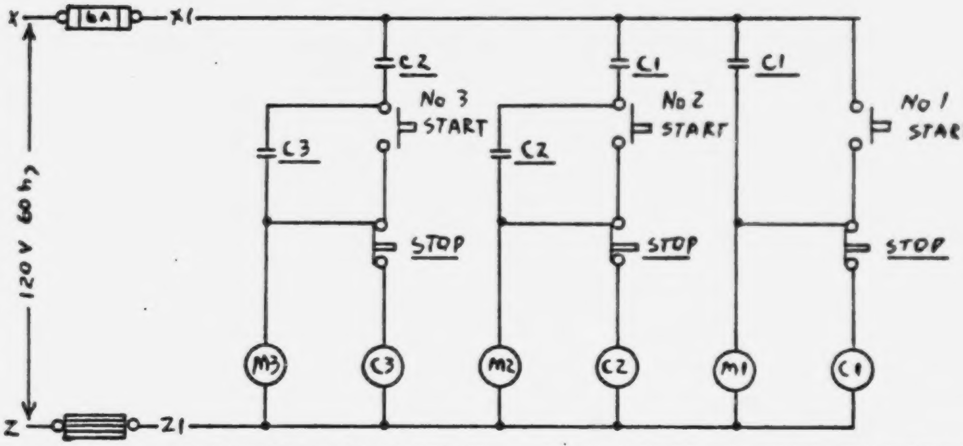
THIS SCHEME IS WIRED SO CONTACTORS CAN BE SWITCHED FROM ONE DIRECTION TO THE OTHER WITHOUT PUSHING THE STOP BUTTON. THIS DIAGRAM IS DRAWN USING LAMPS INSTEAD OF MOTORS AND SHOULD BE WIRED UP IN THE CLASSROOM.

EACH STUDENT SHOULD IDENTIFY THE PUSH BUTTON TERMINALS BY REFERRING TO THE WIRING DIAGRAM & PLACE THE CORRECT NUMBER INSIDE THE ⬡ ON THE SCHEMATIC.

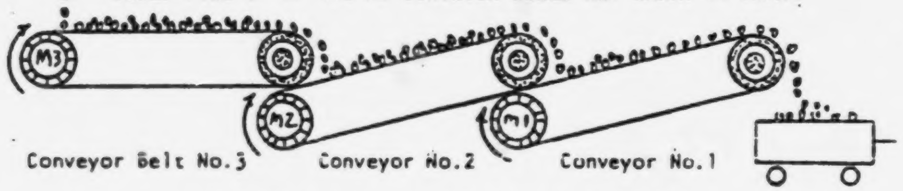

FWD
1
2
3
4
REV
5
6
7
8
STOP
9
10
PUSH BUTTON STATION (FRONT CONNECTED)
2
1
4
3
FWD
6
5
8
HGA
7
REAR VIEW
2
1
4
3
REV
6
5
8
HGA
7
RED LAMP
T1
REV
T2
GREEN LAMP
T1
FOR
T2
6A
DUMMY FUSE
120 VOLT - 60 HZ

WIRING DIAGRAM

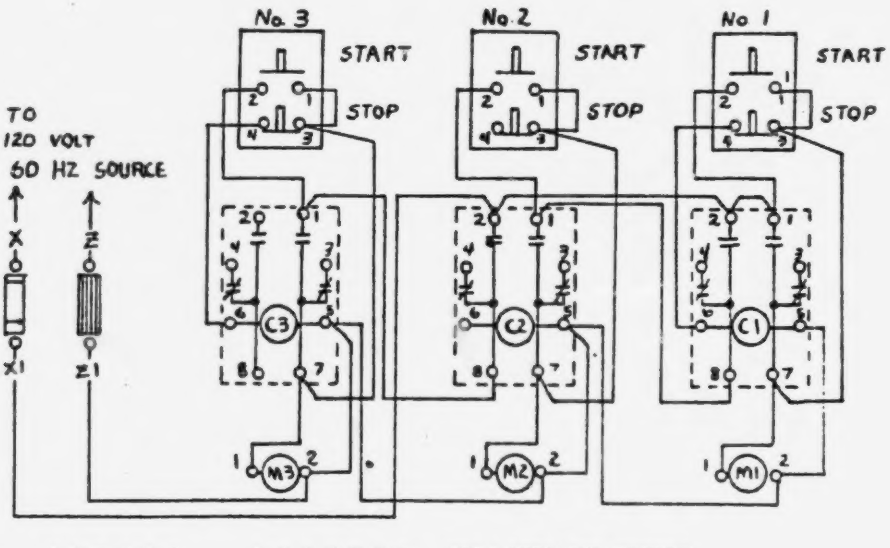
RELAYS ARRANGED FOR SEQUENCE CONTROL OF A CONVEYOR SYSTEM. STUDENTS CAN WIRE THIS IN THE CLASSROOM. RELAYS SIMULATE MOTOR CONTACTORS.


X
6A
X1
120 V 60 hz
Z
Z1
C2
No 3 START
C3
STOP
C1
No 2 START
C2
STOP
C1
No 1 START
STOP
M3
C3
M2
C2
M1
C1

M2 CANNOT BE STARTED UNTIL M1 IS RUNNING AND M3 CANNOT BE STARTED UNTIL M2 IS RUNNING. THIS IS NECESSARY IF M1 IS DRIVING A CONVEYOR FED BY ANOTHER CONVEYOR DRIVEN BY M2. MATERIAL FROM THE M2 CONVEYOR WOULD PILE UP IF THE M1 CONVEYOR COULD NOT CARRY IT AWAY.


M3
M2
M1
Conveyor Belt No.3
Conveyor No.2
Conveyor No.1

TYPICAL APPLICATION


TO
120 VOLT
60 HZ SOURCE
X
Z
X1
Z1
No. 3
No. 2
No. 1
START
STOP
C3
C2
C1
M3
M2
M1

WIRING DIAGRAM - USE LAMPS FOR MOTORS

Lesson 2-8-1
ELECTRICAL PRINT READING

The small one-line schematic in the upper right-hand corner of page 190 shows a circuit breaker containing multi-ratio bushing current transformers for both the source side of the line side of the breaker. The source side CT's are to be connected to the over-current relays connected for a ratio of 600 amp to 5 amp. The load side current transformers are to be connected to the recording-demand watt-hour meter and thermal-demand ammeters with a CT ratio of 400 to 5.

Check-up: (2-8-1)

1. Place the correct wire group letters in the blank circles to match up the wire groups.

2. Complete the connections to the CT terminal blocks, observing the correct polarity and ratio as is on the one-line schematic and three-line wiring diagram.

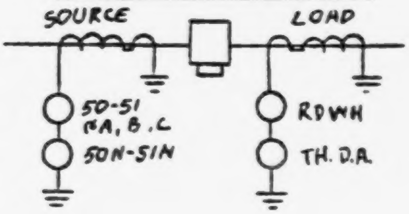
3. Label the wires at the CT terminal blocks - C1, C2, C3, and C0 to correspond to A, B, C, and common (i.e., the wire that carries A-phase current should be labeled C1, the wire that carries B-phase current should be labeled C2, etc.).

4. On page 191 is a three-line schematic. The breaker is shown at the bottom of the page, the meters and relays are shown above. You will find brackets numbered 1 to 32. These brackets are to be used to identify the CT terminal block terminal designations, the type FT-1 test switch letters, meter terminal numbers, or relay terminal numbers. Refer to the wiring diagrams on page 190.

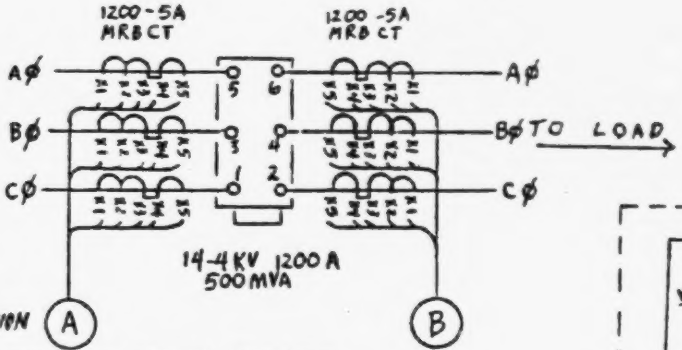
PRINT READING EXERCISE:

label C1, C2, C3, CO for both sets, observe the polarity of the connections as per the one line diagram.

ONE LINE SCHEMATIC

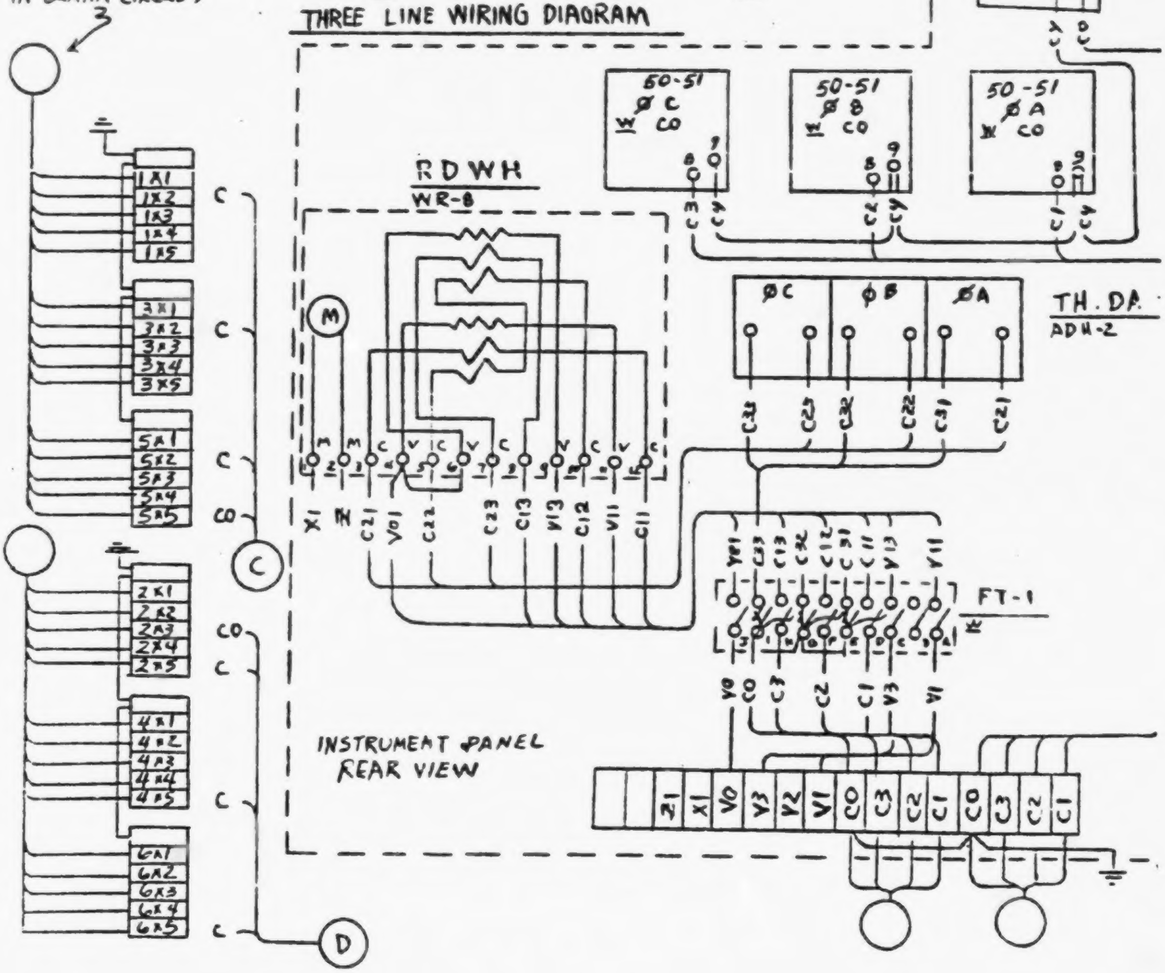

SOURCE
LOAD
50-51 ØA, B, C
50N-51N
RDWH
TH. D.A.

1200-5A	MRCT
TAPS	RATIO
X2 – X3	100
X1 – X2	200
X1 – X3	300
X4 – X5	400
X3 – X4	500
X2 – X4	600
X1 – X4	800
X3 – X5	900
X2 – X5	1000
X1 – X5	1200


1200-5A MRBCT
1200-5A MRB CT
AØ
BØ
CØ
AØ
BØ TO LOAD
CØ
5
6
3
4
1
2
14.4KV 1200A
500MVA
A
B

PLACE WIRE GROUP IDENTIFICATION IN BLANK CIRCLES

THREE LINE WIRING DIAGRAM


50-51 N W CO
50-51 ØC W CO
50-51 ØB W CO
50-51 ØA W CO
8
9
C3
CY
C2
C1
RDWH
WR-8
M
TH. DA
ADH-2
ØC
ØB
ØA
C32
C23
C32
C22
C31
C21
1X1
1X2
1X3
1X4
1X5
3X1
3X2
3X3
3X4
3X5
5X1
5X2
5X3
5X4
5X5
2X1
2X2
2X3
2X4
2X5
4X1
4X2
4X3
4X4
4X5
6X1
6X2
6X3
6X4
6X5
C
CO
C
D
X1
M
C21
V01
C22
C23
C13
V13
C12
V11
C11
FT-1
V0
C0
C3
C2
C1
V3
V1
INSTRUMENT PANEL
REAR VIEW
Z1
X1
V0
V3
V2
V1
C0
C3
C2
C1
C0
C3
C2
C1

Print Reading Exercise: Check-up: (2-8-1) Note that the same C.T. connections are shown below on a three line schematic.

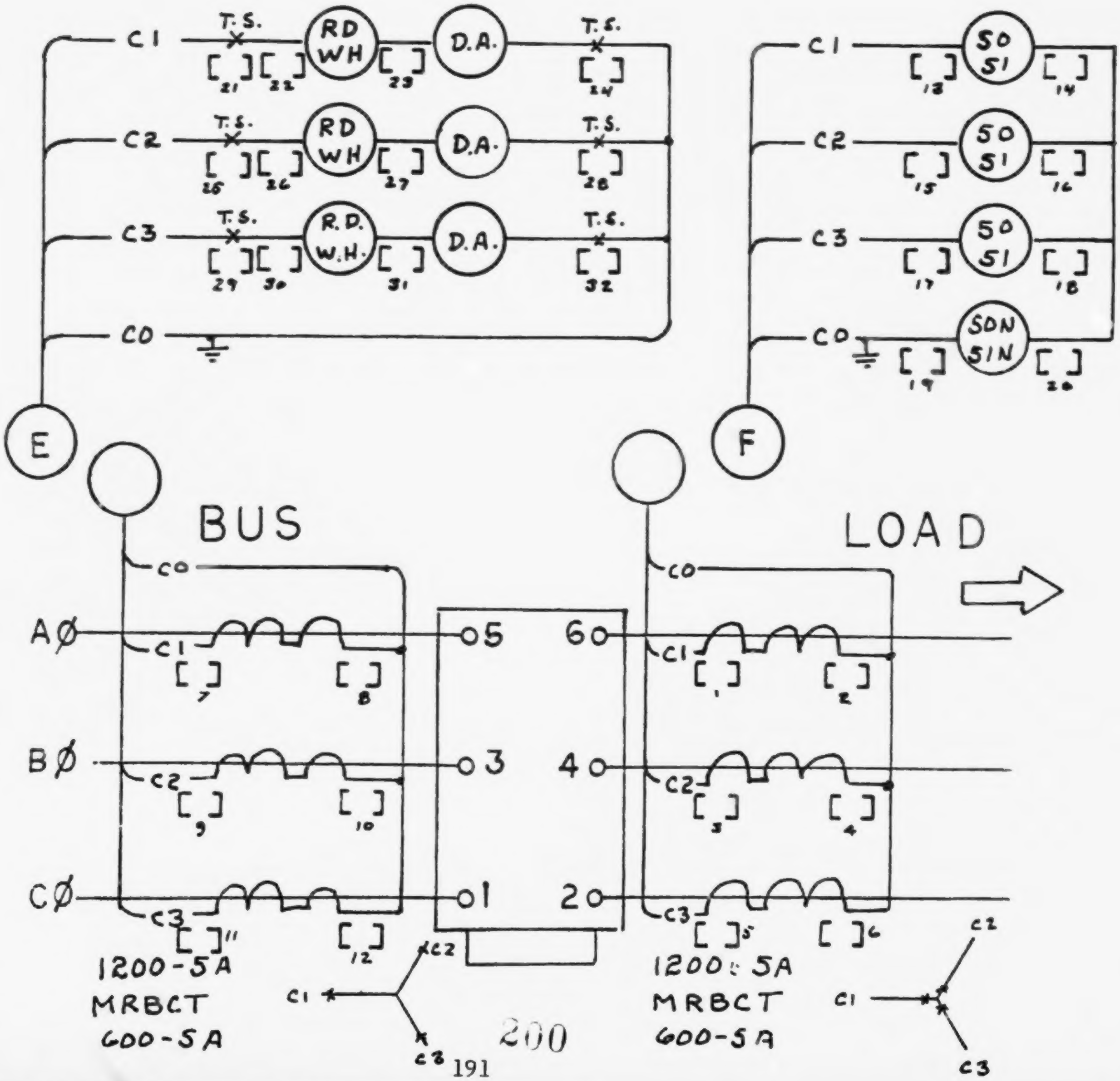
Identify the C.T. terminal block connections used in this application by placing the correct C.T. terminal in the brackets adjacent to the C.T. secondary wire.

Place the wire group identification letter in the correct circles.

Identify the relay terminals by placing the correct number of the terminal in the brackets adjacent to the relay. In the same manner identify the RDWH meter terminals.

Each FT-1 test switch is identified with a letter ("A" through "J"). Place the correct letter in the $\underline{\overset{\text{T.S.}}{\times}}$ brackets.

THREE LINE SCHEMATIC



C1
C2
C3
C0
T.S.
RD WH
R.D. W.H.
D.A.
[ ] 21
[ ] 22
[ ] 23
[ ] 24
[ ] 25
[ ] 26
[ ] 27
[ ] 28
[ ] 29
[ ] 30
[ ] 31
[ ] 32
50 51
50N 51N
[ ] 13
[ ] 14
[ ] 15
[ ] 16
[ ] 17
[ ] 18
[ ] 19
[ ] 20
E
F
BUS
LOAD
AØ
BØ
CØ
5
6
3
4
1
2
[ ] 7
[ ] 8
[ ] 9
[ ] 10
[ ] 11
[ ] 12
[ ] 1
[ ] 2
[ ] 3
[ ] 4
[ ] 5
[ ] 6
1200-5A MRBCT 600-5A
1200-5A MRBCT 600-5A
C1
C2
C3

Lesson 2-8-2
ELECTRICAL PRINT READING

For Print Reading Exercise: Check-up: 2-8-2 (this is an example of the "lineless diagram"). The example on page 193 is a manufacturer diagram of a 115 kv oil circuit-breaker mechanism. Note that each device on the switchgear is assigned an arbitrary letter, or set of letters. Every wire has been coded for identification by a number or letter, or a combination of both. Also note that the same "wire number" does not appear on both ends of the wire. This number is intended to tell what device and terminal on that device (terminal block, fuse, etc.) will be found on the opposite end of the wire. For example, on the right side of the terminal strip labeled "T" is a wire affixed to terminal 35 with the wire number "E1". When locating the device which has been assigned the letter "E", it will be noted that it is the motor fuse block, and affixed to terminal 1 is a wire with the wire number "T35". This shows that this particular wire provides a circuit from terminal block "T35" and the motor fuse block terminal "1".

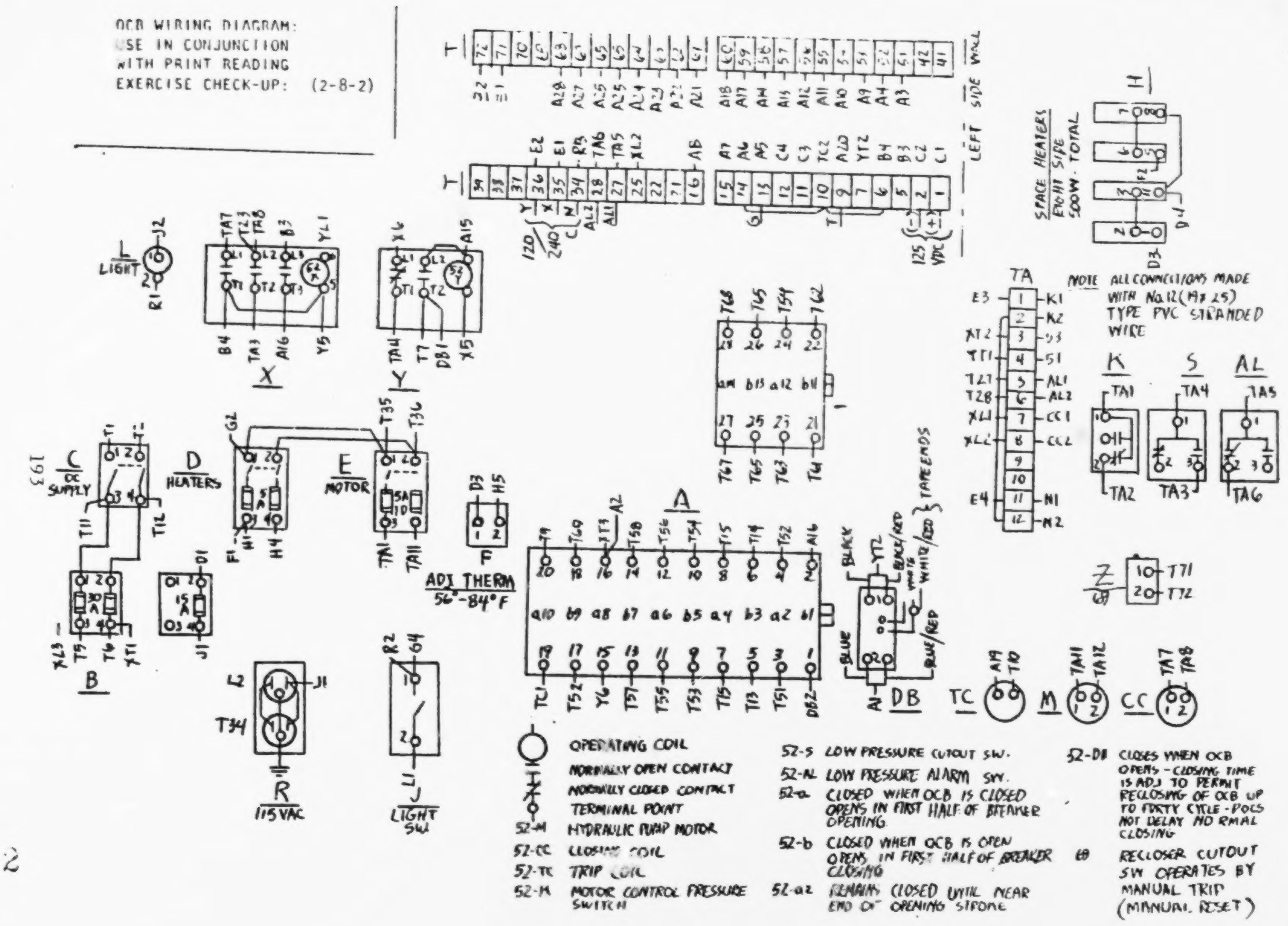
In this type of point-to-point diagram, the "wire number" is derived from the identification letters on the devices, and their studs or terminal numbers.

In another example, terminal block "T", a wire is connected to terminal 60 labeled "A18". The opposite end of this wire will be found on the auxiliary switch "A", terminal 18, and labeled with wire number "T60". Short jumpers, connections between terminals on the same device, are usually shown in full and do not bear any lead identification.

Check-up: (2-8-2)

For the schematic diagram of this breaker (page 194), few of the terminals are identified. Adjacent to the terminal or device, however, you will find a parenthesis with a number inside. The problem is to assign the correct terminal point, device terminal, or ASA device number, that coincides with the number enclosed in the parenthesis.

OCB WIRING DIAGRAM:
USE IN CONJUNCTION
WITH PRINT READING
EXERCISE CHECK-UP: (2-8-2)


T
LEFT SIDE WALL
SPACE HEATERS
E7011 SIDE
500W. TOTAL
H
L
LIGHT
X
Y
C
DC SUPPLY
D
HEATERS
E
MOTOR
F
ADJ THERM
56°-84°F
A
TAPE ENDS
BLACK
BLUE
BLUE/RED
WHITE/RED
DB
TC
M
CC
B
R
115VAC
J
LIGHT SW
TA
K
S
AL
TA1
TA2
TA3
TA4
TA5
TA6
Z
69
T71
T72
120
240
125 VDC
193

NOTE ALL CONNECTIONS MADE WITH No.12(19x25) TYPE PVC STRANDED WIRE

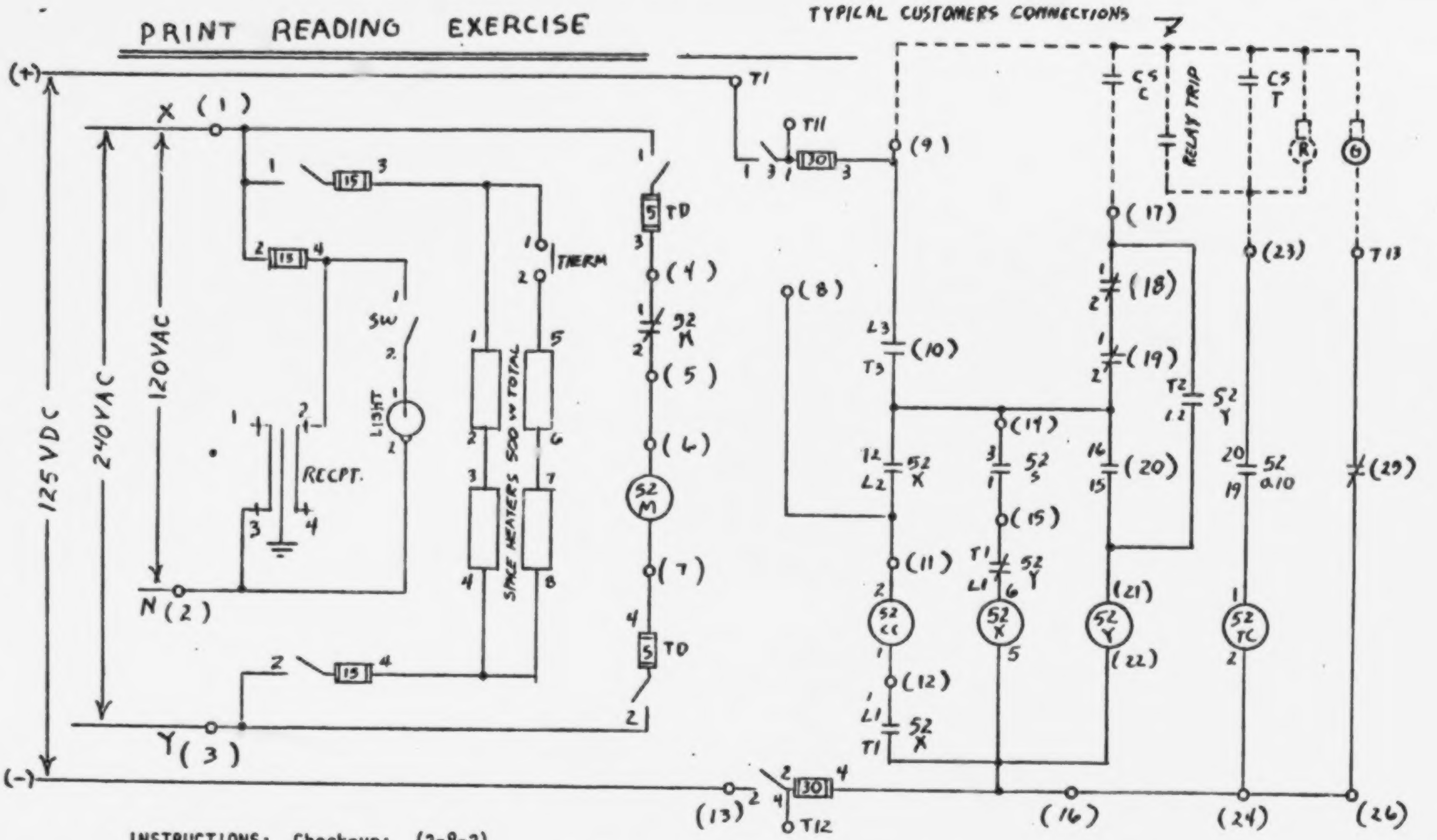
OPERATING COIL
NORMALLY OPEN CONTACT
NORMALLY CLOSED CONTACT
TERMINAL POINT

52-M HYDRAULIC PUMP MOTOR
52-CC CLOSING COIL
52-TC TRIP COIL
52-M MOTOR CONTROL PRESSURE SWITCH

52-S LOW PRESSURE CUTOUT SW.
52-AL LOW PRESSURE ALARM SW.
52-a CLOSED WHEN OCB IS CLOSED OPENS IN FIRST HALF OF BREAKER OPENING
52-b CLOSED WHEN OCB IS OPEN OPENS IN FIRST HALF OF BREAKER CLOSING
52-a2 REMAINS CLOSED UNTIL NEAR END OF OPENING STROKE

52-DB CLOSES WHEN OCB OPENS - CLOSING TIME IS ADJ TO PERMIT RECLOSING OF OCB UP TO FORTY CYCLE - DOES NOT DELAY NORMAL CLOSING
69 RECLOSER CUTOUT SW OPERATES BY MANUAL TRIP (MANUAL RESET)

PRINT READING EXERCISE


TYPICAL CUSTOMERS CONNECTIONS
(+)
(-)
125VDC
240VAC
120VAC
X (1)
N (2)
Y (3)
T1
T11
T12
T13
(9)
(13)
(16)
(24)
(26)
15
13
30
TD
THERM
SW
LIGHT
RECPT.
SPACE HEATERS 500 W TOTAL
52 M
(4)
(5)
(6)
(7)
(8)
(10)
(11)
(12)
(14)
(15)
(17)
(18)
(19)
(20)
(21)
(22)
(23)
(25)
52 X
52 S
52 Y
52 CC
52 TC
52 a10
CS C
CS T
RELAY TRIP
R
G

INSTRUCTIONS: Check-up: (2-8-2)
Refer to the wiring diagram that accompanies this schematic and assign the correct terminal point or device number that will replace the number that appears enclosed within the parenthesis on this diagram - for example:

(1) = T35
(2) = _____
(3) = _____

(4) = _____
(5) = _____
(6) = _____
(7) = _____
(8) = _____
(9) = _____
(10) = _____

(11) = _____
(12) = _____
(13) = _____
(14) = _____
(15) = _____
(16) = _____
(17) = _____

(18) = _____
(19) = _____
(20) = _____
(21) = _____
(22) = _____
(23) = _____
(24) = _____

(25) = _____
(26) = _____

Lesson 2-8-3

LINELESS WIRING DIAGRAM

On pages 198 and 199 is an example of another kind of lineless diagram. This is a print of a motor-operated disconnect mechanism. Note that the wires are not shown as lines between the device terminals, but are listed on a chart next to the diagram. Even the short jumpers and connections between terminals on the same device are listed.

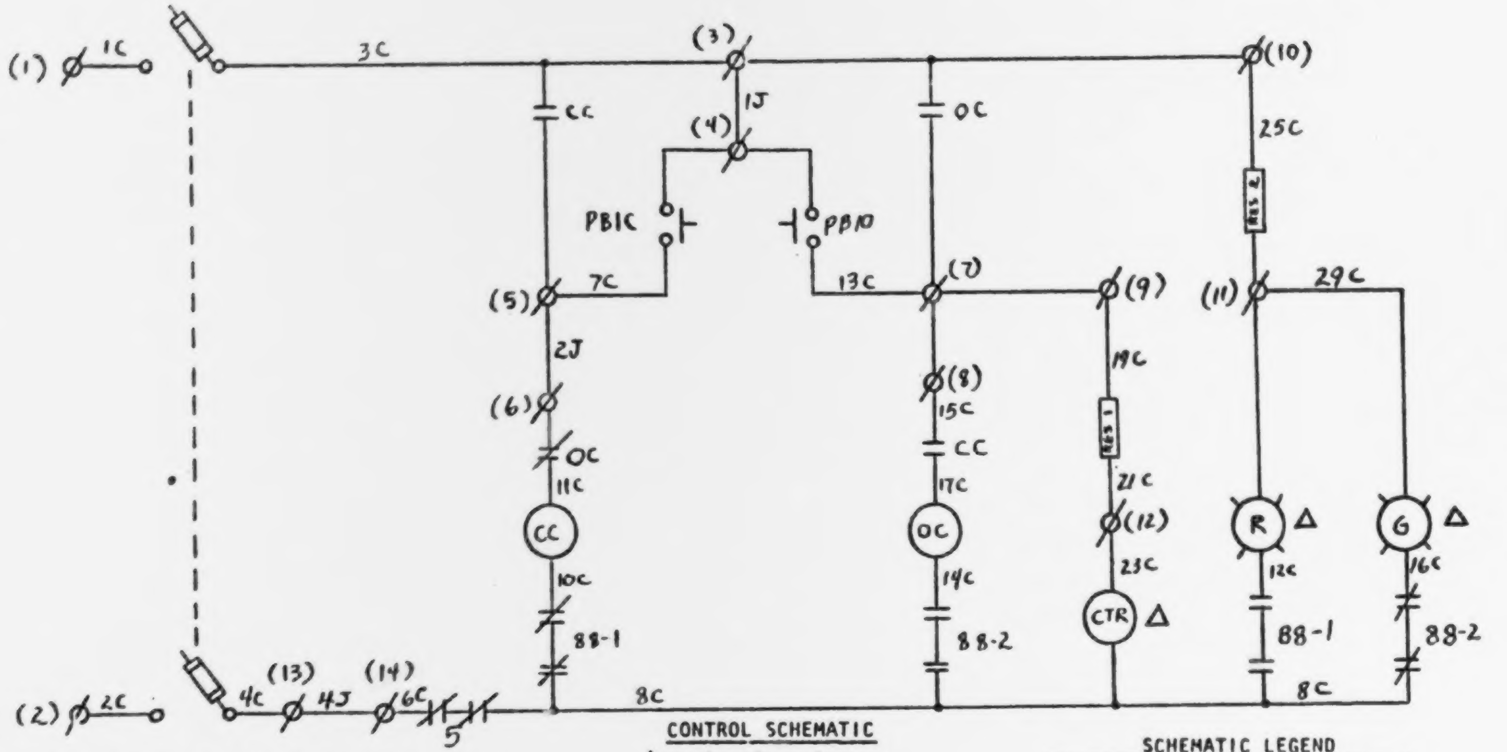
The devices are all assigned an arbitrary letter, or pair of letters. All terminals on the devices have also been assigned numbers. Every physical wire has been coded by number, or by a letter and number (called "wire numbers"). A second column tells the reader where the wires terminate. For example: the first wire listed on the chart is wire number "1C". The location says wire "1C" provides a circuit from the terminal block labeled "TA" terminal "3" to the control fuse block labeled "MD" terminal 5. This system is used for the entire wiring diagram.

Check-up: (2-8-3A)

On page 196 you will find the schematic diagram for the control of the motor-operated disconnect-switch mechanism. Note the parentheses adjacent to the terminal block connection symbols with a number inside. Be able to identify each terminal block connection number (i.e., TA1, TA2, TA3, etc.) by referring to the wire chart and wiring diagram on pages 198 and 199.

Check-up: (2-8-3B)

On page 199 is the motor schematics for the motor-operated disconnect. Some customers who order this equipment choose the dc series motor, others choose the dc compound motor; both are shown here. Identify the terminal points and contacts shown in parentheses.


(1)
1C
3C
(3)
(10)
CC
1J
(4)
OC
25C
PBIC
PBIO
RES 2
(5)
7C
13C
(7)
(9)
(11)
29C
2J
(8)
19C
(6)
15C
CC
RES 1
OC
11C
17C
21C
(12)
CC
OC
R
G
10C
14C
23C
12C
16C
CTR
88-1
88-2
88-1
88-2
(2)
2C
4C
(13)
4J
(14)
6C
5
8C
8C

CONTROL SCHEMATIC

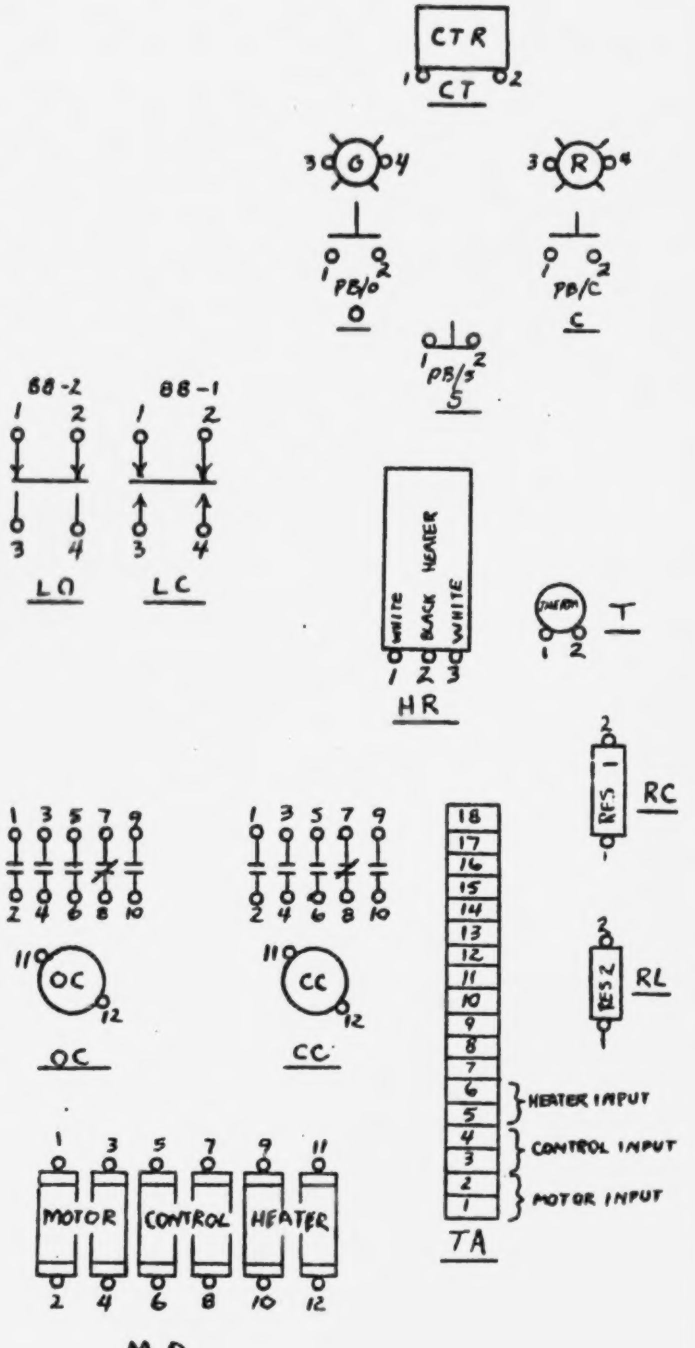
Δ optional equipment
Ø terminal block connection

IDENTIFY THE FOLLOWING TERMINAL BLOCK CONNECTIONS SHOWN IN PARENTHESIS ON THE ABOVE SCHEMATIC. REFER TO THE WIRE CHART & WIRING DIAGRAM ON PAGE

(1)_____
(2)_____
(3)_____
(4)_____
(5)_____
(6)_____
(7)_____
(8)_____
(9)_____
(10)_____
(11)_____
(12)_____
(13)_____
(14)_____

SCHEMATIC LEGEND

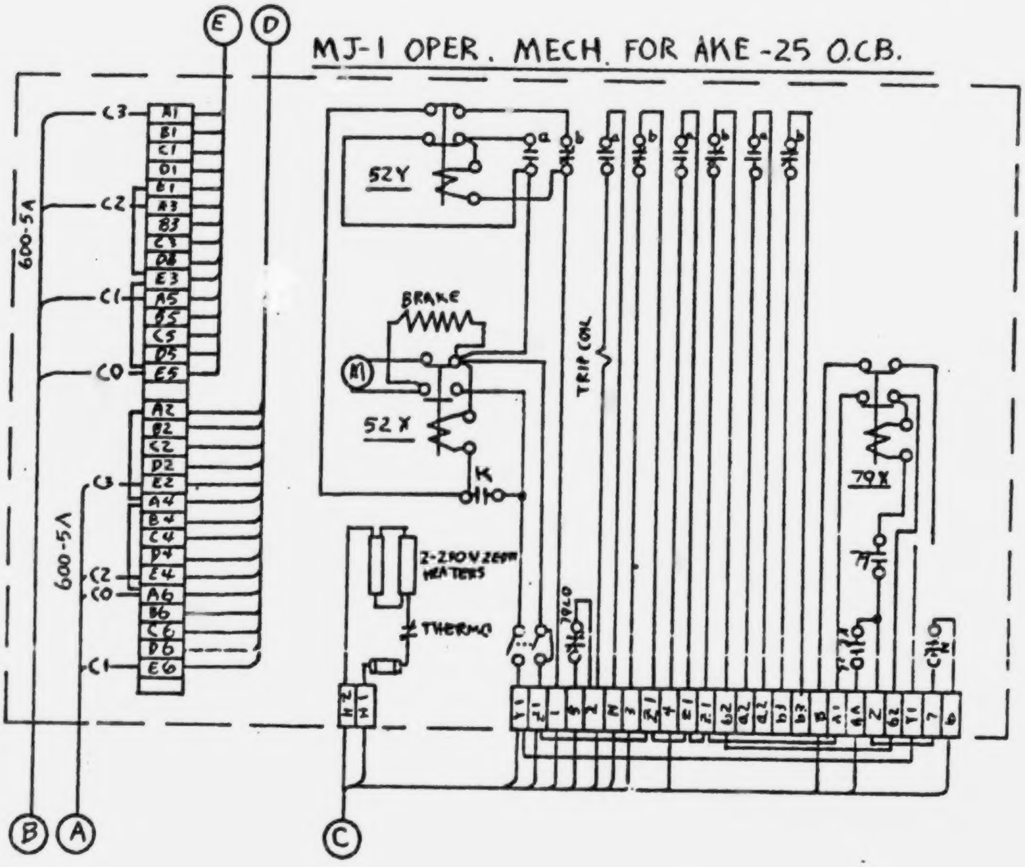
8	Fused Knife Switch
23	Thermostat
OC	Open Contactor
CC	Closed Contactor
88	Motor
BK	Solenoid Brake
CTR	Operation Counter
G	Green Indicating Light (Open)
R	Red Indicating Light (Closed)
88-2	Closed Except in Mechanism Open Position
88-1	Closed except in Mechanism Closed Position
5	Hand Crank Interlock


CTR
CT
G
R
PB/O
O
PB/C
C
PB/S
S
88-2
88-1
LO
LC
WHITE
BLACK HEATER
WHITE
HR
THERM
T
RES 1
RC
RES 2
RL
OC
CC
TA
HEATER INPUT
CONTROL INPUT
MOTOR INPUT
MOTOR
CONTROL
HEATER
MD

WIRE No.	LOCATION
1C	TA3-MD5
2C	TA4-MD7
3C	MD6-TA7-TA15-CC9-OC9
4C	MD8-TA13
5C	TA8-O1-C1
6C	O1-TA14
7C	TA9-OC10-C2
8C	CT2-O2-LC1-LC3-LO1-LO3
9C	TA10-OC7
10C	CC11-LC2
11C	CC12-OC8
*12C	LC4-C4
13C	TA11-OC10-O2
14C	OC11-LO2
15C	TA15-TA12-CC7
*16C	LO4-O4
17C	OC12-CC8
*19C	TA16-RC1
*21C	TA18-RC2
*23C	TA18-CT1
*25C	TA15-RL1
*27C	TA17-RL2
*29C	TA17-O3-C3
30C	TA13-S1 } ONLY USED W/STOP P.B.
32C	TA14-S2 }
1J	TA7-TA8 (REMOVE FOR INT OR EXT SELECTOR SW)
2J	TA9-TA10 (CUST. TO REMOVE TO INTERLOCK OPEN CIR)
4J	TA13-TA14 (ONLY USED W/OUT STOP P.B.)
*	OMIT WHEN INTERNAL IND LIGHTS COUNTER ARE NOT REQUIRED
	HEATER CIRCUIT
1H	TA5-MD9
2H	TA6-MD11
4H	MD12-T1
3H	MD10-HR2 } 115 VAC 100W
6H	T2-HR1-HR3 }
3H	MD10-HR1 } 230VAC 100W
6H	T2-HR3 }
	MOTOR CIRCUIT
	(SERIES)
1M	TA1-MD1
2M	TA2-MD3
3M	MD2-MD2-B1
4M	MD4-CC2-DC2
6M	OC1-OC3-CC1-CC3-B2
8M	OC4-OC6
10M	CC4-CC6
12M	OC5-MO1 } CCW OUT PUT TO CLOSE | OC5-MO3 } CW CLOS
14M	CC5MO3 } | CC5-MO1 }
	(COMPOUND)
1M	TA1-MD1
2M	TA2-MD3
3M	MD2-OC1-OC5-CC1-CC5
4M	MD4-MO5-B2
5M	OC2-CC3-MO3 } CW OUTPUT TO CLOSE
7M	CC2-OC3-MO2 }
5M	OC2-CC3-MO2 } CCW OUTPUT TO CLOSE
7M	CC2-OC3-MO3 }
6M	CC4-OC4-MD4
9M	OC6-CC6-MO1-B1

CONTROL VOLTAGE	RES#1	RES#2
48 VDC	430Ω	680Ω
125 VDC	1500Ω	3000Ω

WIRING DIAGRAM DC SERIES OR DC
COMPOUND MOTOR FOR MOTOR
OPERATED DISCONNECT SWITCH

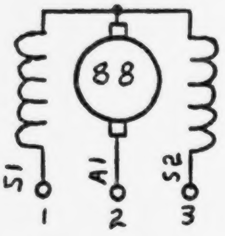


MJ-1 OPER. MECH. FOR AKE-25 O.C.B.

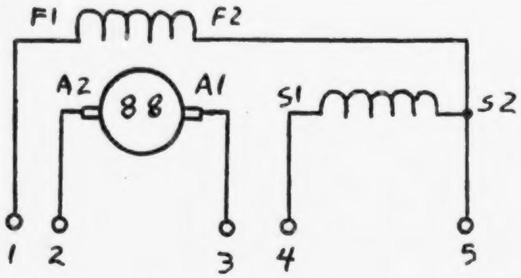
E
D
C3
C2
C1
C0
600-5A
A1
B1
C1
D1
E1
A3
B3
C3
D3
E3
A5
B5
C5
D5
E5
A2
B2
C2
D2
E2
A4
B4
C4
D4
E4
A6
B6
C6
D6
E6
52Y
a
b
BRAKE
M
52X
K
TRIP COIL
79X
74
2-250V ZEPH HEATERS
THERMO
LO
H2
H1
B
A
C

L E G E N D

A.C.C.		Automatic Closing Cutout
50-51		Phase Overcurrent Relay Inst & Time Delay Trip
50N-51N		Ground Overcurrent Relay Inst & Time Delay Trip
52CS		O.C.B. Control SW.
52		O.C.B.
	a	Aux SW. Closed When O.C.B. Is Closed
	b	Aux. SW. Closed When O.C.B. is Open
	M	Spring Winding & Closing Motor
	X	Motor Contactor
	Y	Closing Cutoff Relay
	K	Motor Limit SW.
	Z	Cut Out SW. Opens When O.C.B. is tripped Manually Resets When O.C.B. is Closed
	TC	Trip Coil
79		Reclosing Timer, MT-3
	BA	Alarm Contact
	LO	Timer Lock-Out Contact Opens After First Reclosure Closes When Timer Resets
79X		Aux. Relay for Timer
74		Alarm Relay


88
S1
A1
S2
1
2
3

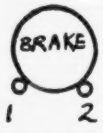
DC SERIES


F1
F2
A2
88
A1
S1
S2
1
2
3
4
5

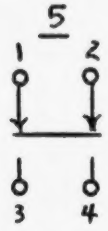
DC COMPOUND

MO

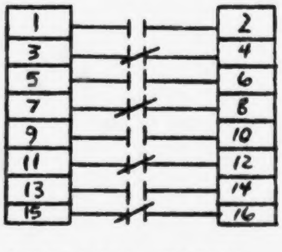
EXAMPLE OF A LINELESS WIRING DIAGRAM FOR A MOTOR OPERATED DISCONNECT SWITCH EITHER DC SERIES OR DC COMPOUND MOTOR WILL BE SUPPLIED USER MUST SPECIFY.



B



D


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

AUXILIARY SWITCH

MOTOR VOLTAGE	INRUSH VOLTAGE	FULL LOAD CURRENT
48 VDC	67A	23A
125 VDC	35A	9A

Lesson 2-8-4

DIAGRAMS FOR CAPACITOR BANK CONTROL

On pages 206 through 210 are diagrams for the control of a 3,600 KVAR capacitor bank such as might be in use in a distribution substation. On page 206 is shown the three-line diagram. The switching of the capacitor bank is accomplished by closing or opening of the vacuum switch. This may be done in a manual mode or in an automatic mode. In either case, the vacuum switch is made to close electrically.

The manual mode can be selected with the "43" (selector) switch, a single-pole, double-throw switch. In this mode of operation, the operator must turn the device "number 52" control switch to the "close" position when it is desirable to close the vacuum switch. Likewise, the operator can open the vacuum switch by turning the "52" control switch to the "open" position. The "52" control switch is a General Electric type SB1 (commonly used for breaker control).

The control of the vacuum switch is interlocked with the ground switch to prevent inadvertently closing the vacuum switch when the ground switch is closed, or vice versa. This is to prevent shorting and grounding the energized bank, which would produce disastrous results. Short circuit protection is provided, otherwise, by current-limiting fuses.

Capacitor cans come equipped with internal bleeder resistors and will, when the capacitor bank is de-energized, bleed the stored charge from the can in three to five minutes. Most manufacturers recommend waiting a minimum of five minutes after de-energizing a capacitor before closing the ground switch or re-energizing the bank.

The control also has an "automatic" mode of operation and can be placed in service with the "43" (auto-manual selector) switch. In the automatic mode of operation, the WF CONTROLLER (device #1-1) will control the switching of the vacuum switch. The controller amounts to a sophisticated wattmeter with contacts that will close to switch the capacitor bank in, when the load through the main power transformer builds up to some preset value, and to switch the capacitor off when the load falls below a preset value. The three-line diagram shows the current transformer and potential transformer that supply secondary current and voltage to the wattmeter element of the controller.

Overvoltage protection is provided by a General Electric type IAV relay. The overvoltage contacts are set to close (after a slight time delay) for 110 percent and above of normal voltage. The IAV relay is also equipped with a set of contacts for undervoltage (in this case, they should be thought of as normal voltage) set to close at 105 percent and below the normal voltage level.

Underfrequency protection is frequently installed in distribution stations such as this. You will find a contact of the underfrequency relay shown on the ac schematic; however, the relay is located in another part of the substation, not included in this set of drawings. Each individual capacitor can is protected from short circuits or internal faults by a capacitor fuse and, as mentioned previously, the entire bank is protected by current limiting fuses.

CAPACITOR CONTROL WIRING DIAGRAM

Check-up: (2-8-4)

Instructions: Select the answer that is the most accurate.

1. The "2-1" time delay relay when first energized:
   ______ (a) blocks opening of the vacuum switch
   ______ (b) blocks closing of the vacuum switch
   ______ (c) blocks both opening and closing of the vacuum switch
   ______ (d) turns on the green indicating lamp

2. The "2-1" time delay relay will become energized:
   ______ (a) when the vacuum switch is first closed
   ______ (b) some adjustable time (3 to 5 minutes) after the vacuum switch is opened
   ______ (c) when the "43" switch is on automatic and the vacuum switch is opened
   ______ (d) anytime the vacuum switch is opened

3. The "2T-1" timing relay, if energized, will:
   ______ (a) remove the potential from the master control relay
   ______ (b) close the vacuum switch, if the "43" switch is in the automatic mode
   ______ (c) trip the vacuum switch with no regard to the position of the "43" selector switch
   ______ (d) trip the vacuum switch only when the "43" switch is made automatic

4. The 59X relay will be picked up (operated) whenever:
   ______ (a) there is a short circuit on the capacitor bank
   ______ (b) the 120/240 volt-ac gets above a preset value of volts
   ______ (c) the 120 volt-ac bus potential gets above a preset value of volts
   ______ (d) the 48 volt-dc gets above a preset value of volts

5. The 59X relay will be reset or dropped:
   ______ (a) overvoltage on the 120/240 volt-ac circuit
   ______ (b) undervoltage on the 48 volt-dc
   ______ (c) anytime the 43 switch is made manual
   ______ (d) low voltage on the 120 volt-ac bus potential

6. The kirk key interlock used on the ground switch for the capacitor bank has a set of contacts, numbers 2 and 7 that are:
   ______ (a) closed whenever the vacuum switch is open
   ______ (b) open whenever the ground switch is closed
   ______ (c) closed whenever the ground switch is closed
   ______ (d) closed whenever the 94 relay has operated

7. The terminal block numbers on the vacuum switch to which the wires are connected that provide dc power to the vacuum switch are:
______ (a) 1 for positive, 2 for negative
______ (b) 3 for positive, 4 for negative
______ (c) 7 for positive, 9 for negative
______ (d) 1 for negative, 2 for positive

8. The 59X relay, when operated, blocks closing of the vacuum switch:
______ (a) when in the automatic mode
______ (b) when in the manual mode
______ (c) when in either manual or automatic mode
______ (d) until the "2-1" time delay relay times out

9. Contacts 2 and 3 of the 52X relay when closed:
______ (a) will energize the vacuum switch closing coil
______ (b) seal in the 52X coil
______ (c) de-energize the 52Y relay
______ (d) probably blow the 48 volt-dc control fuse

10. The wires connecting to the 52Y relay coil are labeled:
______ (a) 3A and 3B
______ (b) 3 and 3A
______ (c) 3B and 7
______ (d) 1A and 2A

11. The 59X relay operate coil cannot be picked up (energized) unless:
______ (a) the vacuum switch is closed
______ (b) the kirk key interlock is adjusted correctly
______ (c) the "43" switch is made automatic
______ (d) the master controller is working properly

12. When the 43 switch is in automatic mode:
______ (a) the 52 control switch, if operated, will open the breaker--not close it
______ (b) close the breaker, but not open it
______ (c) allow the master controller to open the breaker when the frequency gets too high
______ (d) permit the master controller to control the breaker for preset load conditions

13. Assume the breaker has tripped out and for some reason it will not close again, either on manual or automatic. Which of the following is the most logical reason:
______ (a) the master controller "1-1Y" contact is closed
______ (b) the 94 relay is sealed up
______ (c) the electric counter is not operating
______ (d) the 2-1 time delay relay has you blocked

14. Assume the breaker is in the closed position and the red indicating lamp is not burning - it should be. The most logical reason is:
______ (a) the "43" switch is on manual mode
______ (b) one of the 120/240 volt-20 fuses located in the capacitor control cabinet has blown
______ (c) the 120 volt-ac bus potential has been interrupted
______ (d) the 30-amp, 48-volt negative fuse is blown

15. Term 6 on the "1-1" contact making wattmeter is "hot" to ground (i.e., it has a voltage of 120-volts to ground). This is an indication that:
______ (a) the potential coil of the controller could be open circuited
______ (b) the potential coil could be shorted out
______ (c) the FT-1 test switch "A" could be open
______ (d) the FT-1 test switch "B" could be open

16. Referring to the master controller:
______ (a) relay coil 1-1Y and relay coil 1-1X are operating from a half-wave rectifier circuit
______ (b) relay coil 1-1X and relay coil 1-1Y operate from a full-wave rectifier
______ (c) 1-1Y operates from ac and 1-1X operates from dc
______ (d) 1-1Y operates on dc and 1-1X operates on ac

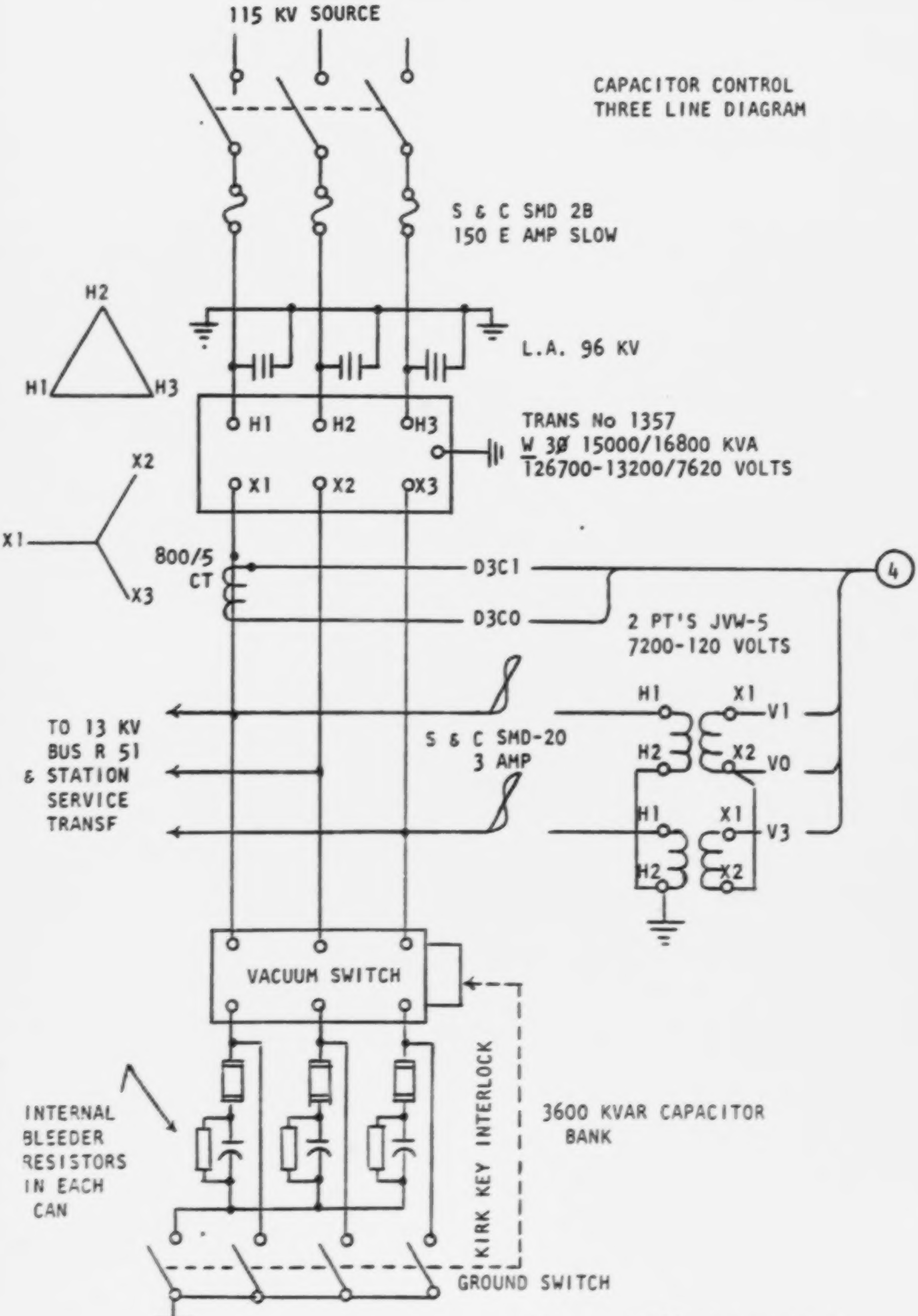
17. The master controller device No. 1-1 is a contact making wattmeter. When the load through the main power transformer reaches a preset value of kilowatts, the contacts of the meter close and de-energize the 1-1X relay coil:
______ (a) which de-energizes the 1-1Y relay and thus trips the 94 relay
______ (b) and energizes the 1-1Y relay which seals in through its own contact
______ (c) by shorting out the 1-1X relay coil
______ (d) so as to reduce the load on the isolatin transformer

18. The ration of the auxiliary current transformer is such that:
______ (a) when 1 amp flows in the primary circuit, 2 amps flow to the current coil of the master controller
______ (b) 4 amps in the primary will produce only 2 amps in the secondary
______ (c) it will equal the ration of the potential transformer
______ (d) the current vector will be more in phase with the potential transformer vector

19. Assume the breaker is open and a voltmeter with terminal 27 to terminal 28 (capacitor control cabinet) shows a potential of approximately 48 volts-dc. This would seem to indicate that the:
_____ (a) green lamp is working and verifies the breaker is open
_____ (b) auxiliary switch contacts 12 and 13 on the vacuum switch have an air gap (i.e., the wiring is incomplete)
_____ (c) the EC (operation counter) must have counted an operation
_____ (d) the "2-1" agastat relay is energized

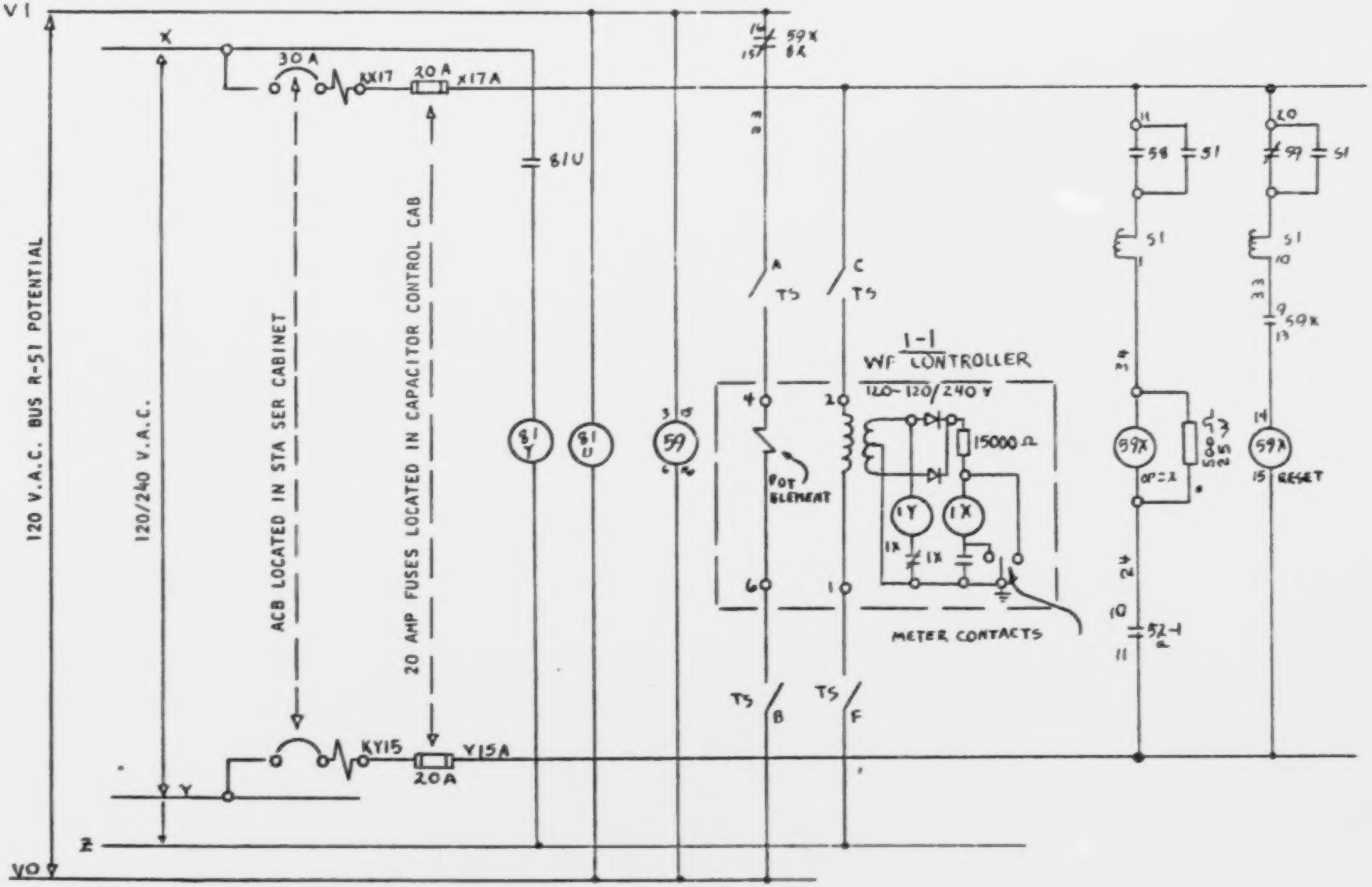
20. In accordance with the National Electric Code, all high voltage cells must be equipped with internal resistors for the purpose of discharging the cells after line potential has been removed. One should keep in mind, however, that the capacitor may retain a dangerous charge for several minutes. As a safety margin it is best not to re-energize the capacitors for approximately 5 minutes. The relay in the control circuit that supervises this function is:
_____ (a) the "2T-1" timing relay
_____ (b) the 1-1 master controller
_____ (c) the "2-1" timing relay

CAPACITOR CONTROL
THREE LINE DIAGRAM

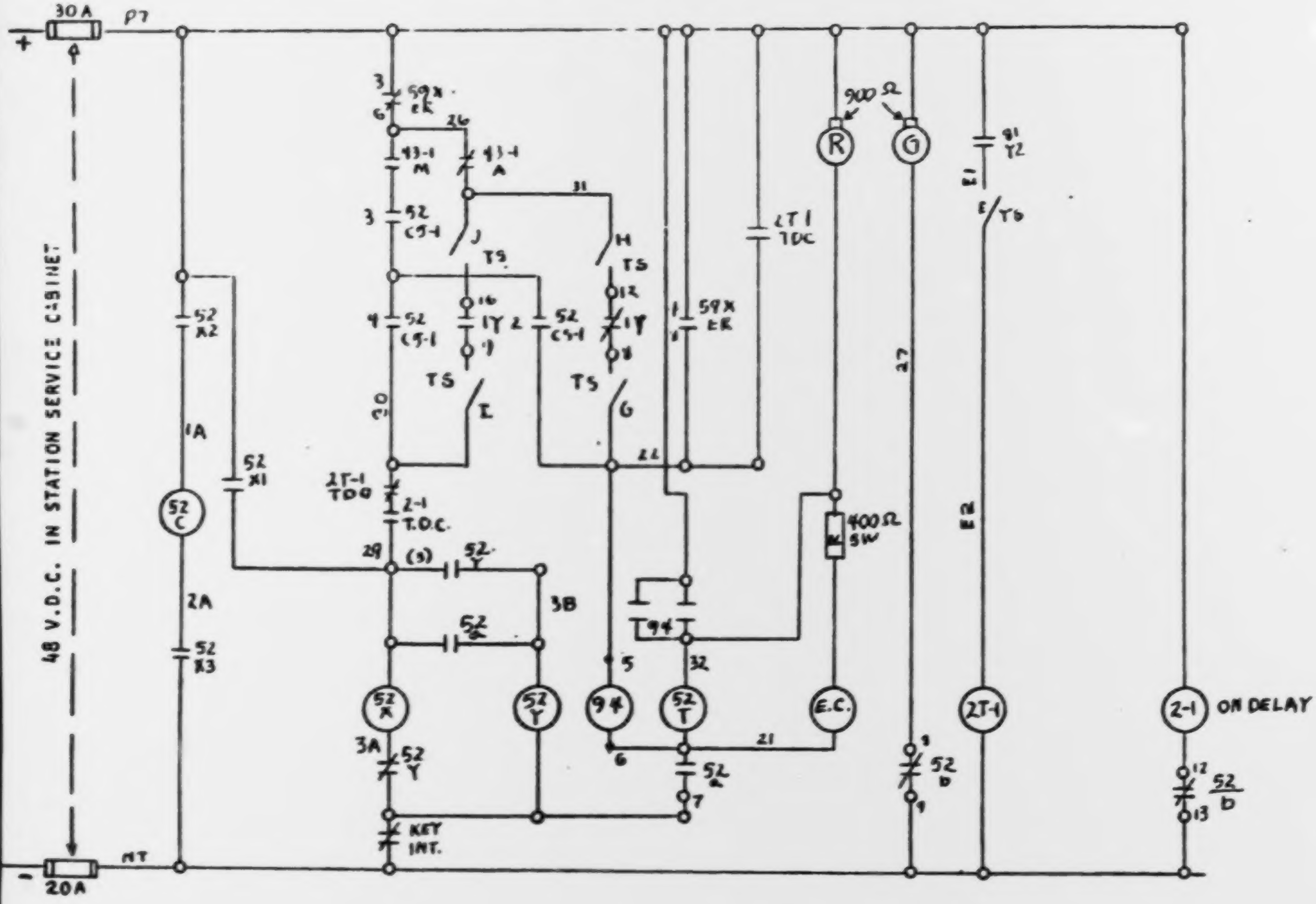

115 KV SOURCE
S & C SMD 2B
150 E AMP SLOW
H2
H1
H3
L.A. 96 KV
H1
H2
H3
TRANS No 1357
W 3Ø 15000/16800 KVA
T26700-13200/7620 VOLTS
X1
X2
X3
X2
X1
X3
800/5
CT
D3C1
D3C0
4
2 PT'S JVW-5
7200-120 VOLTS
TO 13 KV
BUS R 51
& STATION
SERVICE
TRANSF
S & C SMD-20
3 AMP
H1
X1
V1
H2
X2
V0
H1
X1
V3
H2
X2
VACUUM SWITCH
KIRK KEY INTERLOCK
INTERNAL
BLEEDER
RESISTORS
IN EACH
CAN
3600 KVAR CAPACITOR
BANK
GROUND SWITCH

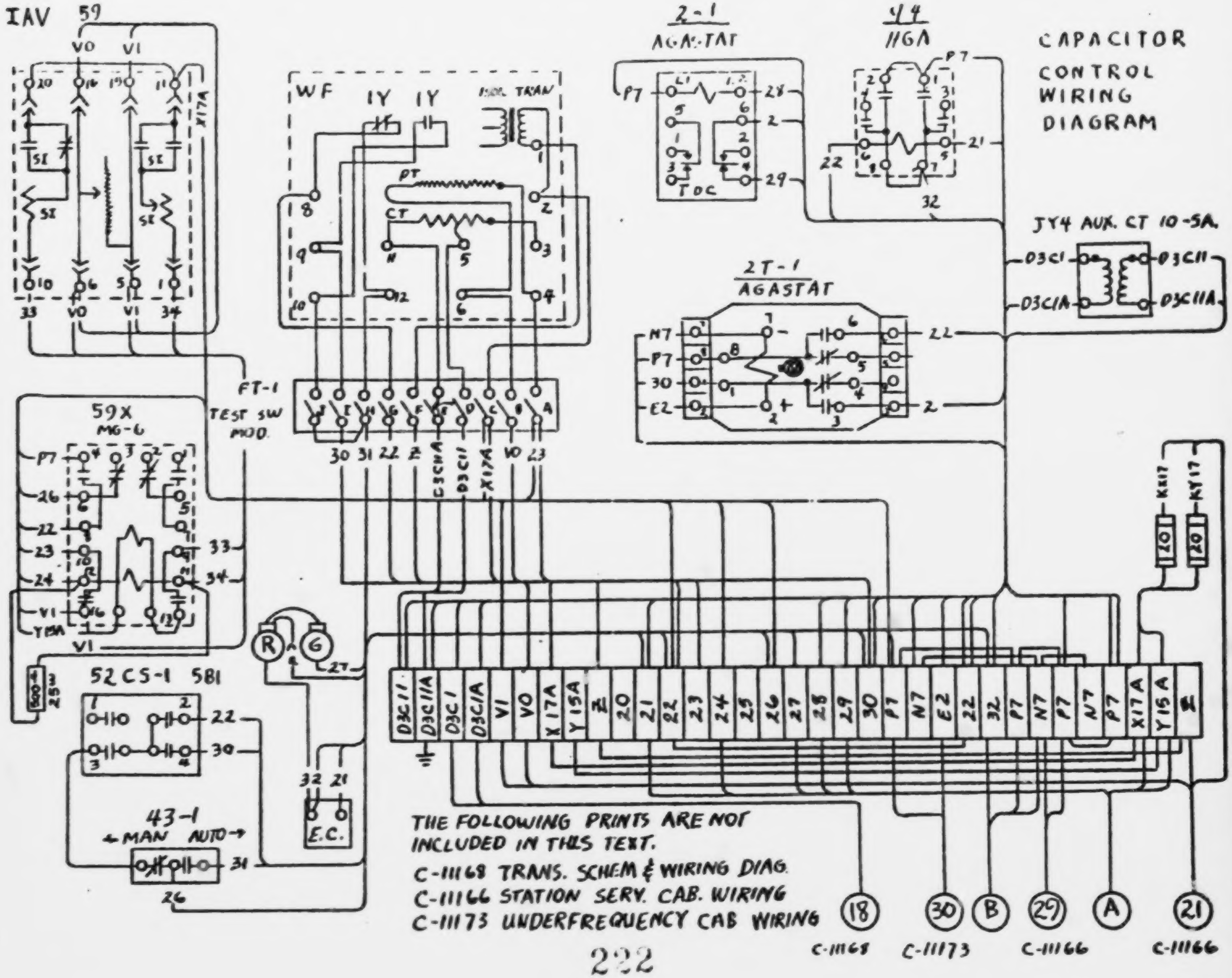
NOTE: C-11166 STATION SERV.
CAB. WIRING DIAGRAM
NOT INCLUDED IN THIS SET.

CAPACITOR CONTROL A-C SCHEMATIC DIAGRAM


V1
X
30 A
XX17
20 A
X17A
14
59X
15
BR
33
81U
A
TS
C
TS
11
58
51
20
59
51
51
1
51
10
33
9
59X
13
34
120 V.A.C. BUS R-51 POTENTIAL
120/240 V.A.C.
ACB LOCATED IN STA SER CABINET
20 AMP FUSES LOCATED IN CAPACITOR CONTROL CAB
81 Y
81 U
3
59
15
4
1-1
WF CONTROLLER
120-120/240 V
4
2
15000 Ω
POT ELEMENT
1Y
1X
1X
1X
6
1
METER CONTACTS
59X
OP=X
500 25
14
59X
15
RESET
24
10
52-1
a
11
TS
B
TS
F
KY15
Y15A
20A
Y
Z
VO

CAPACITOR CONTROL D-C SCHEMATIC DIAGRAM


30A
P7
+
48 V.D.C. IN STATION SERVICE CABINET
-
20A
NT
52 X2
1A
52 C
2A
52 X3
52 X1
59X ER
43-1 M
43-1 A
26
31
52 CS-1
TS
J
H
16
1Y
12
52 CS-1
TS
I
G
2T-1 TDO
2-1 T.D.C.
29
(5)
52 Y
52 a
3B
52 X
52 Y
3A
KEY INT.
94
52 T
5
32
6
7
21
22
2T1 TDC
59X ER
R
G
900 Ω
400Ω 5W
E.C.
27
52 b
91 Y2
E/Y6
2T-1
2-1
ON DELAY
52 b
12
13

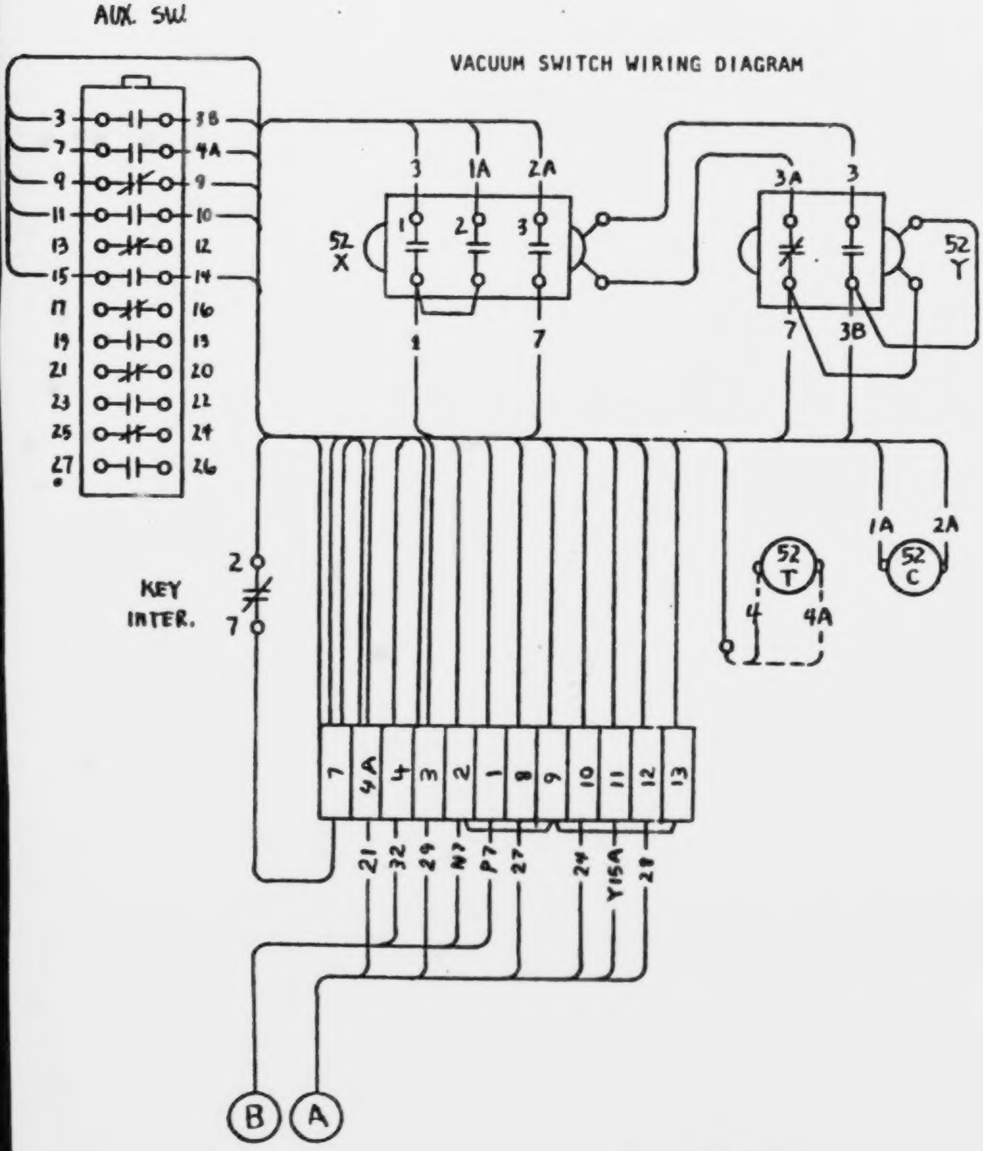

IAV
59
VO
VI
X17A
33
VO
VI
34
WF
1Y
1Y
MOD. TRAN
PT
CT
FT-1
TEST SW
MOD.
30
31
22
Z
D3C11A
D3C11
X17A
VO
23
59X
MG-6
P7
26
22
23
24
V1
Y15A
33
34
V1
R
G
27
52CS-1
SB1
22
30
43-1
← MAN
AUTO →
31
26
32
21
E.C.
2-1
AGASTAT
P7
28
2
29
TDC
Y4
11GA
P7
22
21
32
JY4 AUX. CT 10-5A
D3C1
D3C11
D3C1A
D3C11A
2T-1
AGASTAT
N7
P7
30
E2
22
2
KX17
KY17
D3C11
D3C11A
D3C1
D3C1A
V1
VO
X17A
Y15A
Z
20
21
22
23
24
25
26
27
28
29
30
P7
N7
E2
22
32
P7
N7
P7
N7
P7
X17A
Y15A
Z
18
30
B
29
A
21
C-11168
C-11173
C-11166
C-11166

CAPACITOR CONTROL WIRING DIAGRAM

THE FOLLOWING PRINTS ARE NOT INCLUDED IN THIS TEXT.

C-11168 TRANS. SCHEM & WIRING DIAG.
C-11166 STATION SERV. CAB. WIRING
C-11173 UNDERFREQUENCY CAB WIRING

VACUUM SWITCH WIRING DIAGRAM


AUX. SW.
3
3B
7
4A
9
9
11
10
13
12
15
14
17
16
19
18
21
20
23
22
25
24
27
26
KEY INTER.
2
7
52 X
3
1A
2A
1
2
3
1
7
52 Y
3A
3
7
3B
52 T
4
4A
1A
2A
52 C
7
4A
4
3
2
1
8
9
10
11
12
13
21
32
29
N7
P7
27
24
Y15A
28
B
A

DEVICE NUMBER
AND FUNCTION

1-1	Master Control Contact - Making Wattmeter
	1X Pilot Relay
	1Y Control Relay
52	
TC	Trip Coil
X	Closing Aux. Relay
C	Closing Coil
CS	Control Switch
G	Green Light
R	Red Light
43	Manual-Auto Transfer Sw.
59	Overvoltage Relay
59X	Overvoltage Aux. Relay
2	Time Delay Closing Relay
SI	Seal in Element
TS	Test Switch
ER	Electric Reset
EC	Electric Counter
2T-1	Timer
81-Y	Underfrequency Aux. Relay
a	Aux. SW Closes When OCB Closes
b	Aux SW Opens When OCB Closes

Lesson 2-8-5

PRINT READING - TEST YOUR KNOWLEDGE

Check-up: (2-8-5)

Refer to the accompanying elementary and wiring diagrams on pages 214 and 215, and answer the following twenty questions:

1. The wire number that connects the "52Y" relay coil to term block 10 is __________.

2. The wire number for the wire that connects the "63MX" relay coil to a 10-amp time lag fuse is __________.

3. The wire number for the wire that connects the thermostat to the 500-watt, 240-volt heater is __________.

4. The wire number for the wire that connects the 08 fuse to the "52Y" relay coil is __________.

5. The wire number for the jumper that connects term block 6 to term block 10A is __________.

6. The wire number for the wire that connects the light to the duplex receptical is __________.

7. The wire number of the wire that connects the "63MX" relay coil to a contact of the "63M" (pressure regulator) is __________.

8. The wire number of the wire that connects the "63C" contact (pressure switch - lockout prevents operation at low pressure) and a "52b" switch is __________.

9. The wire number of the wire that connects the breaker trip coil to negative is __________.

10. The wire number of the wires that provide the feed to fuse blocks H & M is __________.

11. What level of voltage is to be utilized to operate the motor? __________.

12. With the circuit breaker open and the control power switches closed (energized), would a voltmeter connected to term block 13 indicate 125 volts negative, or 125 volts positive? __________.

13. If in question 12 the circuit breaker were closed, would term block 13 be 125 volts negative, or 125 volts positive? __________.

14. Should term block 3 be connected to a hot wire, or a neutral wire? ___________.

15. A voltmeter connected from wire number 4 to wire number 4A and indicating 120 volts ac would indicate that 08 L 15 amp fuse was blown, true or false? ___________.

16. If a wireman removed and taped the wire connected to term block 36H, would this prevent the heater from operation? ___________.

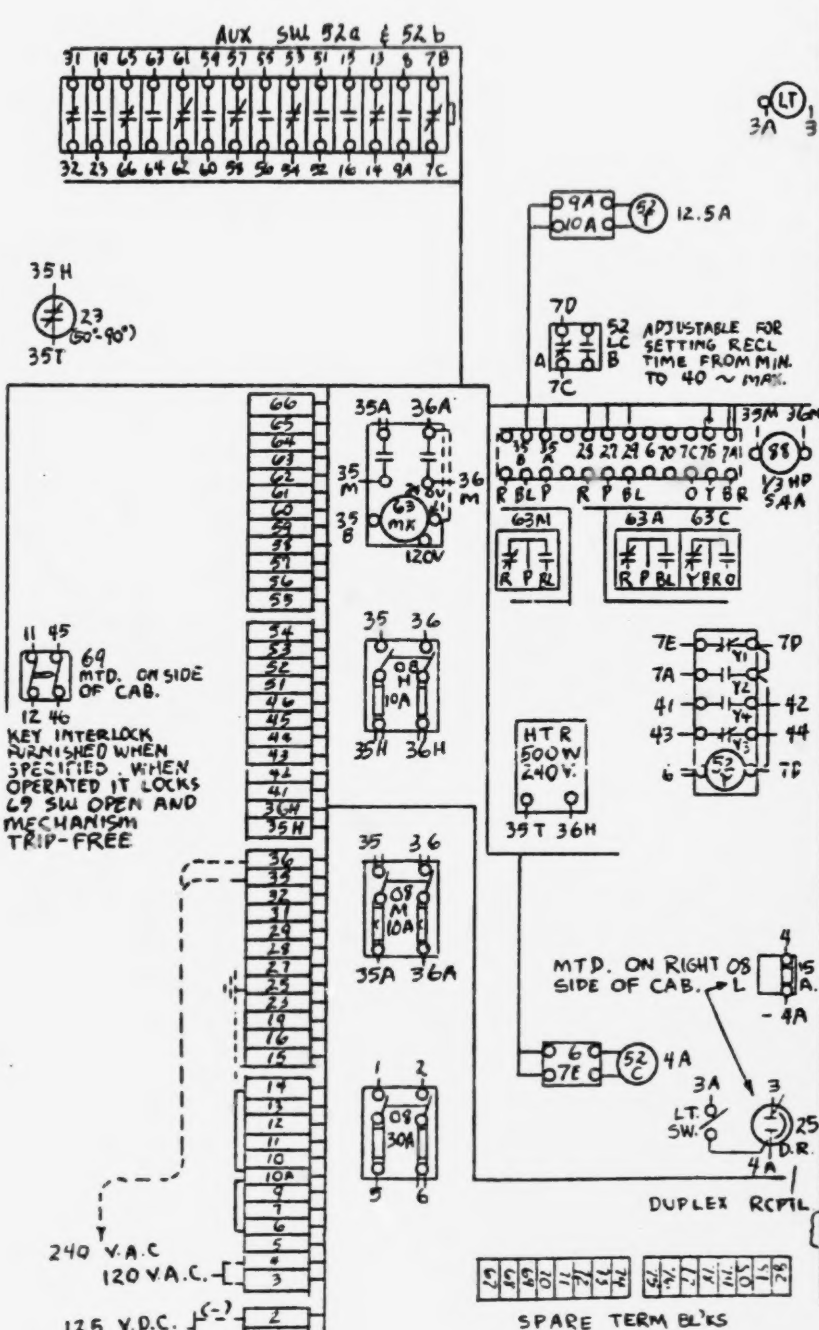
17. The master controller device number 1-1 is a contact making wattmeter. When the load through the main power transformer reaches a preset value of kilowatts, the contacts of the meter close and de-energize the 1-1X relay coil:
   _____ (a) which de-energizes the 1-1Y relay and thus trips the 94 relay
   _____ (b) and energizes the 1-1Y relay which seals in through its own contact
   _____ (c) by shorting out the 1-1X relay coil
   _____ (d) so as to reduce the load on the isolation transformer

18. The ration of the auxiliary current transformer is such that:
   _____ (a) when 1 amp flows in the primary circuit, 2 amps flow to the current coil of the master controller
   _____ (b) 4 amps in the primary will produce only 2 amps in the secondary
   _____ (c) it will equal the ration of the potential transformer
   _____ (d) the current vector will be more in phase with the potential transformer vector

19. Assume the breaker is open and a voltmeter from terminal 27 to terminal 28 (capacitor control cabinet) shows a potential of approximately 48 volts dc. This would seem to indicate that the:
   _____ (a) green lamp is working and verifies the breaker is open
   _____ (b) auxiliary switch contacts 12 and 13 on the vacuum switch have an airgap (i.e., wiring is incomplete)
   _____ (c) the E.C. (operation counter) must have counted an operation
   _____ (d) the "2-1" agastat relay is energized

20. In accordance with the National Electric Code, all high voltage capacitor cells must be equipped with internal resistors for the purpose of discharging the cells after line potential has been removed. One should keep in mind, however, that the capacitor may retain a dangerous charge for several minutes. As a safety margin it is best not to re-energize the capacitors for approximately 5 minutes. The relay in the control circuit that supervises this function is:

_____ (a) the "2T-1" timing relay
_____ (b) the 1-1 master controller
_____ (c) the "2-1" timing relay

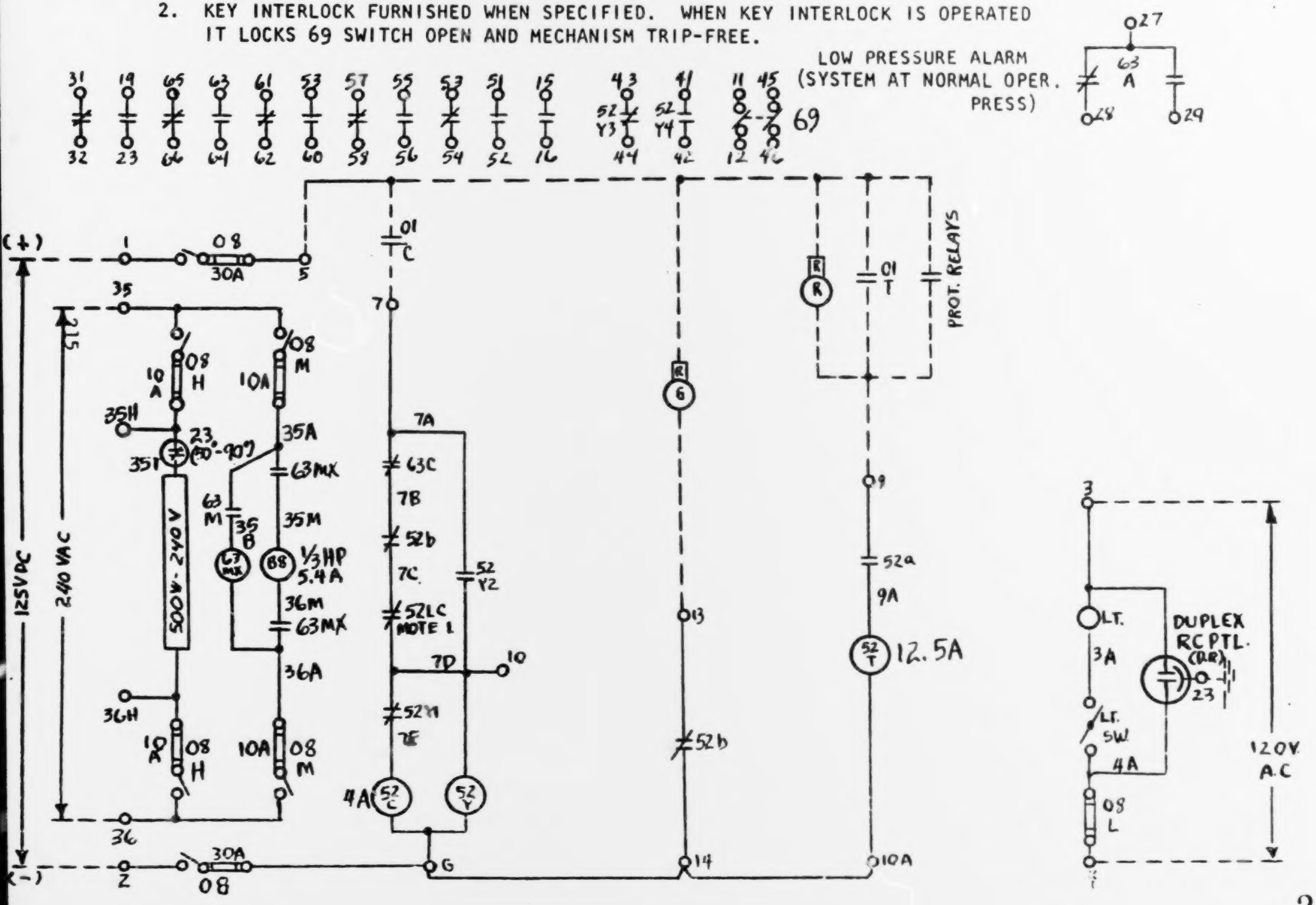

AUX SW 52a & 52b
31 19 65 67 61 59 57 55 53 51 15 13 8 7B
32 23 66 64 62 60 58 56 54 52 16 14 9A 7C
LT
3A
1
3
9A
10A
52 Y
12.5A
7D
52 LC
A
B
7C
ADJUSTABLE FOR SETTING RECL TIME FROM MIN. TO 40 ~ MAX.
35H
23 (50°-90°)
35T
35A 36A
35 M
36 M
35 B
63 MX
120V
35B 35A 23 27 29 6 7D 7C 7B 7A
35M 36M
88
1/3 HP 54A
R BL P R P BL O Y B R
63M
63A 63C
R P BL R P BL Y B R O
35 36
O8 H 10A
35H 36H
7E 7D
Y1
7A Y2
41 42
Y4
43 44
Y3
6 52 Y 7C
11 45
69 MTD. ON SIDE OF CAB.
12 46
KEY INTERLOCK FURNISHED WHEN SPECIFIED. WHEN OPERATED IT LOCKS 69 SW OPEN AND MECHANISM TRIP-FREE
HTR 500W 240V.
35T 36H
35 36
O8 M 10A
35A 36A
1 2
O8 30A
5 6
MTD. ON RIGHT SIDE OF CAB.
O8 L
4
15 A.
4A
6
7E
52 C
4A
3A
LT. SW.
3
25
D.R.
4A
DUPLEX RCPTL
66 65 64 63 62 61 60 59 58 57 56 55
54 53 52 51 46 45 44 43 42 41 36H 35H
36 35 32 31 29 28 27 25 23 19 16 15
14 13 12 11 10 10A 9 7 6 5 4 3 2 1
240 V.A.C
120 V.A.C.
125 V.D.C.
(-)
(+)
SPARE TERM BL'KS

WIRE TABLE		
WIRE NO.	FROM	TO
1	TB-1	O8
2	TB-2	O8
3	TB-3	D.R.
3	D.R.	LT.
3A	LT. SW	LT.
4	TB-4	O8L
4A	O8L	D.R
5	TB-5	O8
6	TB-6	O8
6	O8	52Y
6	52Y	52C
7D	52T	TB-1C
7A	TB7	63C
7A	63C	52Y2
7B	63C	52B
7C	52b	52LC
7D	52LC	52Y1
7E	52Y1	52C
9	TB9	52a
9A	52a	52T
10A	TB10A	52T
13	TB13	52b
14	TB14	52b
15	TB15	52a
16	TB16	52a
19	TB-19	52a
23	TB-23	52a
27	TB-27	63A
28	TB-28	63A
29	TB-29	63A
31	TB-31	52b
32	TB-32	52b
35	TB-35	O8M
35	O8M	O8H
35A	O8M	63MX
35A	63MX	63M
35B	63M	63MX
35M	63MX	88
35H	TB-35H	O8H
35H	O8H	23
35T	23	HTR
36	TB-36	O8M
36	O8M	O8H
36A	O8M	63MX
36H	TB-36H	O8H
36H	O8H	HTR
41	TB-41	52Y4
42	TB-42	52Y4
43	TB-43	52Y3
44	TB-44	52Y3
45	TB-45	69
25	TB-25	D.R.
36M	63MX	88
46	TB46	69
AUX. SW.		
51	TB-51	52a
	THRU	
66	TB-66	52b
JUMPERS		
6	TB-6	TB10A
10A	TB10A	TB14
63MX	1	REQ
52Y	2	REQ
LT SW & DR.	1	REQ
11	TB-11	69
12	TB-12	69

227

NOTES: 1. TIMED LATCH CHECK SWITCH TRANSFERS IMMEDIATELY ON O.C.B. TRIP.
ADJUSTABLE FOR SETTING RECLOSING TIME FROM MINIMUM TO 60 CYCLES MAXIMUM.

2. KEY INTERLOCK FURNISHED WHEN SPECIFIED. WHEN KEY INTERLOCK IS OPERATED IT LOCKS 69 SWITCH OPEN AND MECHANISM TRIP-FREE.



LOW PRESSURE ALARM
(SYSTEM AT NORMAL OPER. PRESS)
27
63 A
28
29
31 32
19 23
65 66
63 64
61 62
53 60
57 58
55 56
53 54
51 52
15 16
43 44
52 Y3
41 42
52 Y4
11 12
45 46
69
(+)
(-)
1
08
30A
5
2
01 C
7
35
36
215
240 VAC
125 VDC
08 H
10 A
08 M
10A
35H
35I
23 (80°-90°)
35A
63MX
63 M
35 B
35M
LT MX
88
1/3 HP 5.4A
500W.-240V
36M
63MX
36A
36H
7A
63C
7B
52b
7C
52 Y2
52LC NOTE 1
7D
10
52H
7E
4A
52 C
52 Y
G
R
6
13
52b
14
R
01 T
PROT. RELAYS
9
52a
9A
52 T
12.5A
10A
3
LT.
3A
LT. SW.
4A
08 L
DUPLEX RCPTL. (RR)
23
120V. A.C

DEVICE NUMBERS AND FUNCTIONS

1 MASTER ELEMENT is the initiation device, such as a control switch, voltage relay, float switch, etc., which serves either directly, or through such permissive devices as protective and time delays, to place an equipment in or out of operation.

2 TIME-DELAY STARTING or CLOSING RELAY is one which gives a desired amount of time delay between operations in an automatic sequence.

3 (Reserved for future application.)

4 MASTER CONTACTOR or RELAY is a device, generally controlled by device number 1, or equivalent, and the necessary permissive and protective devices, which serves to make and break the necessary control circuits to place an equipment into operation under the desired conditions and to take it out of operation under other, or abnormal, conditions.

5 STOPPING DEVICE is one whose primary function is to place and hold an equipment out of operation.

6 STARTING CIRCUIT BREAKER, CONTACTOR, OR SWITCH is a device whose principal function is to connect a machine to its source of starting voltage.

7 ANODE CIRCUIT BREAKER is one used in the anode circuits of a power rectifier primarily to interrupt the rectifier circuit on arc back.

8 CONTROL POWER SWITCH is a manually-operated switch or circuit breaker used for the express purpose of connecting and disconnecting the source of control power to and from the control bus or equipment.

9 REVERSING DEVICE is one which is used to reverse the shunt-field connections of a synchronous converter during the starting sequence, or for other special reversing functions.

10 UNIT SEQUENCE SWITCH is one which is used to change the sequence of placing units in and out of service in multiple-unit equipment.

11 CONTROL POWER TRANSFORMER is a transformer which serves as the source as an ac control power for operating ac devices.

12 OVERSPEED DEVICE is usually a direct-connected speed switch which functions on machine overspeed.

13 SYNCHRONOUS-SPEED DEVICE is one which operates at approximately normal synchronous speed of a machine, such as

a centrifugal-speed switch, a slip-frequency relay, a voltage relay, an undercurrent relay, or any type of device which functions at approximately normal machine speed.

14 UNDERSPEED DEVICE is one which functions on machine speed below a desired value.

15 SPEED REGULATING DEVICE is one which functions to hold the speed or frequency of a machine or system at a certain value, or between certain limits.

16 BATTERY-CHARGING CONTROL DEVICE is the battery charger; namely a motor-generator set, tube or plate-type rectifier, etc.

17 SERIES FIELD SHUNTING CIRCUIT BREAKER or CONTACTOR serves to open and close a shunt circuit around a machine series field.

18 ACCELERATING or DECELERATING CIRCUIT BREAKER, CONTACTOR, or RELAY is one which is used to close, or cause the closing of, circuits for bringing a machine up to speed or shutting it down.

19 STARTING TO RUNNING TRANSITION CONTACTOR or RELAY operates to cause the transfer of a machine from the starting to the running power connections.

20 ELECTRICALLY OPERATED VALVE is a solenoid or motor-operated valve in vacuum, air, oil, or water line, etc., or one used for braking purposes.

21 IMPEDANCE RELAY is one which functions when the circuit impedance increases or decreases to a predetermined value.

22 EQUALIZER CIRCUIT BREAKER or CONTACTOR serves to make and break the equalizer or current-balancing connections for machine field, or machine voltage regulators, in a multiple-unit installation.

23 TEMPERATURE REGULATING DEVICE is one which functions to hold the temperature of a machine or other apparatus between certain limits.

24 BUS TIE CIRCUIT BREAKER, CONTACTOR, or SWITCH serves to connect buses or bus sections together.

25 SYNCHRONIZING or PARALLELING DEVICE is one which operates when two ac circuits are within the desired limits of voltage, frequency, and/or phase angle, to permit or cause the paralleling of these two circuits.

26 APPARATUS THERMAL DEVICE is one which functions at desired high and/or low operating-temperature values or limits of the apparatus to which it is applied.

27 AC UNDERVOLTAGE RELAY is one which functions on a given value of single-phase ac undervoltage.

28 RESISTOR THERMAL DEVICE is one which functions upon excessive load indicating, limiting, or shifting resistor temperature.

29 ISOLATING CIRCUIT BREAKER, CONTACTOR, or SWITCH is one used for the express purpose of disconnecting one circuit from another for purposes of emergency operating, maintenance, or test.

30 ANNUNCIATOR RELAY is a nonautomatic reset device which gives a number of separate visual indications upon the functioning of protective devices, and may also be arranged to perform the lockout function.

31 SEPARATE EXCITATION DEVICE is one which connects a circuit such as a synchronous converter shunt field to a source of separate excitation during the starting sequence, or for energizing the excitation and ignition circuits of a power rectifier.

32 DC REVERSE POWER RELAY or DEVICE is one which functions on a given value of dc reverse power.

33 POSITION SWITCH is one which makes or breaks contact when the main device or piece of apparatus, which has no device-function number, reaches a given position.

34 MOTOR-OPERATED SEQUENCE SWITCH is one which fixes the operating sequence of the major devices during starting and stopping, or during other sequential-switching operations.

35 BRUSH-OPERATING or SLIP-RING SHORT-CIRCUITING DEVICE is one for raising, lowering, or shifting the brushes of a machine, or for short-circuiting the slip rings.

36 POLARITY DEVICE is one which operates or permits the operation of another device on a given polarity only.

37 UNDERCURRENT or UNDERPOWER RELAY is one which functions on a given minimum of current or power flow.

38 BEARING THERMAL DEVICE is one which functions on excessive bearing temperatures.

39 FIELD REDUCING CONTACTOR is one which inserts resistance in the field circuit of a machine or otherwise reduces its field excitation.

40 FIELD RELAY is one which functions on a given value of machine field current.

41 FIELD CIRCUIT BREAKER, CONTACTOR, or SWITCH is a device which functions to apply, and/or remove, the machine field excitation.

42 RUNNING CIRCUIT BREAKER, CONTACTOR, or SWITCH is a device whose principal function is to connect a machine to its source of running voltage.

43 TRANSFER DEVICE is a manually-operated device which transfers the control circuits to modify the plan of operation of the switching equipment or of some of the devices.

44 UNIT SEQUENCE STARTING CONTACTOR or RELAY is one which functions to start the next available unit in a multiple-unit equipment on failure of nonavailability of normal preceding unit.

45 DC OVERVOLTAGE RELAY is one which functions on a given value of dc circuit overvoltage.

46 REVERSE-PHASE, PHASE-BALANCE CURRENT, or POWER RECTIFIER MISFIRE RELAY is one which functions on polyphase current of reverse-phase sequence, or on polyphase current unbalance, or on failure of one or more of the power rectifier anodes to fire.

47 SINGLE- or REVERSE-PHASE VOLTAGE RELAY is one which functions upon a given value of polyphase voltage of the desired phase sequence.

48 INCOMPLETE SEQUENCE RELAY is one which returns the equipment to the normal, or off, position and locks it out if the normal starting, or operating, or stopping sequence is not properly completed within a predetermined time.

49 AC THERMAL RELAY or DEVICE is one which functions when the temperature of the ac machine or apparatus exceeds a given value.

50 SHORT-CIRCUIT SELECTIVE RELAY or DEVICE is one which functions instantaneously on an excessive value of current, or on an excessive rate of current rise, indicating a fault in the apparatus or circuit being protected.

51 AC OVERCURRENT RELAY is one which functions when the current in an ac circuit exceeds a given value.

52 AC CIRCUIT BREAKER or CONTACTOR is one whose principal function is usually to interrupt short-circuit or fault currents.

53 EXCITER or GENERATOR RELAY is one which forces the building up of the dc machine field during starting and/or functions when the machine voltage has built up to a given value.

54 HIGH-SPEED CIRCUIT BREAKER is a circuit breaker which starts to reduce the current in the main circuit in 0.01 second or less, after the occurrence of the dc overcurrent or the excessive rate of current rise.

55 POWER-FACTOR RELAY is one which operates on a given power factor in an ac circuit.

56 FIELD APPLICATION RELAY or DEVICE is used to control automatically the application of ac motor field excitation at some predetermined point in the slip cycle.

57 (Reserved for future application.)

58 (Reserved for future application.)

59 AC OVERVOLTAGE RELAY is one that functions on a given value of ac overvoltage.

60 VOLTAGE BALANCE RELAY is one which operates on a difference in voltage between two circuits.

61 CURRENT BALANCE RELAY is one which operates on difference in current input or output of two circuits.

62 TIME-DELAY STOPPING or OPENING RELAY is one which serves in conjunction with the device which initiates the shutdown, or stopping, or opening indication in an automatic sequence.

63 FLUID PRESSURE, LEVEL, or FLOW RELAY is one which operates on a given value of fluid or gas pressure, or flow, or fluid level.

64 GROUND PROTECTIVE RELAY is one which functions on failure of the insulation of a machine, transformer, or other apparatus, to ground, or on flashover of a dc machine to ground. This function is not applied to devices 51N and 67N connected in the residual or secondary neutral circuit of current transformers.

65 GOVERNOR is the equipment which controls the gate or valve opening of a prime mover.

66 NOTCHING RELAY is one which functions to allow only a specified number of operations of a given device, or equipment, or a specified number of successive operations within a given time of each other. It is also used to allow periodic energizing of a circuit.

67 AC POWER DIRECTIONAL or AC DIRECTIONAL OVERCURRENT RELAY is one which functions on a desired value of overcurrent with ac power flow in a given direction.

68 DC THERMAL RELAY or DEVICE is one which functions when the temperature of the dc machine or apparatus exceeds a given value.

69 PERMISSIVE CONTROL DEVICE is generally a two-position, manually-operated switch which permits the closing of a circuit breaker, or the placing of an equipment into operation in one position, and in the other position prevents operating the circuit breaker or the equipment.

70 ELECTRICALLY-OPERATED RHEOSTAT is one used to vary the resistance of a circuit in response to some means of electrical control.

71 DC LINE EMERGENCY CIRCUIT BREAKER or CONTACTOR is one used to interrupt a dc power circuit under emergency conditions, such as overspeed.

72 DC LINE CIRCUIT BREAKER or CONTACTOR is one used to close and interrupt a dc power circuit under normal conditions and/or to interrupt this circuit under emergency conditions.

73 LOAD RESISTOR CIRCUIT BREAKER or CONTACTOR is one used to shunt or insert a step of load limiting, shifting, or indicating resistance in a power circuit, or to switch a space heater in circuit.

74 ALARM RELAY is one other than an annunciator, as covered under device number 30, which is used to operate, or to operate in connection with, a visual or audible alarm.

75 POSITION CHANGING MECHANISM is used for moving a removable circuit breaker unit to and from the connected, disconnected, and test positions.

76 DC OVERCURRENT RELAY is one which functions when the current in a dc circuit exceeds a given value.

77 IMPULSE TRANSMITTER is used to generate and transmit impulses over a telemetering or pilot-wire circuit to the remote indicating or receiving device.

78 PHASE-ANGLE MEASURING RELAY is one which functions at a predetermined phase angle between voltages or currents, or between voltage and current.

79 AC RECLOSING RELAY is one which controls the reclosing and locking out of an ac circuit interrupter.

80 DC UNDERVOLTAGE RELAY or DEVICE is one which functions on a given value of dc undervoltage.

81 FREQUENCY DEVICE is one which functions on a given value of frequency: either under, over, or normal.

82 DC RECLOSING RELAY is one which controls the closing and reclosing of a dc circuit interrupter, generally in response to load circuit conditions.

83 SELECTIVE CONTROL, or TRANSFER, CONTACTOR or RELAY is one which operates to select automatically between certain sources or conditions in an equipment, or performs automatically a transfer operation.

84 OPERATING MECHANISM is the complete electrical mechanism, including the operating motor, position switches, etc., for a tap changer, induction regulator or similar apparatus.

85 CARRIER or PILOT-WIRE RECEIVER RELAY is one which is operated or restrained by a blocking signal used in connection with carrier current or dc pilot-wire fault directional relaying.

86 LOCKING-OUT RELAY or DEVICE is an electrically operated hand or electrically reset relay or device which functions to shut down and hold an equipment out of service on the occurrence of abnormal conditions.

87 DIFFERENTIAL CURRENT RELAY is a fault-detecting relay which functions on a differential current of a given percentage or amount.

88 AUXILIARY MOTOR or MOTOR GENERATOR is one used for operating auxiliary equipment such as pumps, blowers, exciters, etc.

89 LINE SWITCH is one used as a disconnecting or isolating switch in an ac or dc power circuit, when this device is electrically operated or has electrical accessories, such as auxiliary switches, magnetic lock, etc.

90 REGULATING DEVICE is one which functions to regulate a quantity such as voltage, current, power, etc., at a certain value or between certain limits.

91 DC VOLTAGE DIRECTIONAL RELAY is one which operates when the dc voltage across an open circuit breaker or contactor exceeds a given value in a given direction.

92 DC VOLTAGE and CURRENT DIRECTIONAL RELAY is one which operates in one manner when the dc voltage across an open breaker or contactor exceeds a given value in a given direction, and operates in the opposite manner when the current in the circuit, after the circuit breaker or contactor is closed, exceeds a given value in the opposite direction.

93 FIELD-CHANGING CONTACTOR or RELAY is one which functions to change the value of excitation on a machine.

94 TRIPPING or TRIP-FREE RELAY or CONTACTOR is one which functions to trip a circuit breaker, contactor, or equipment, or to prevent immediate reclosure of a circuit interrupter, in case it opens on overload, even though the original closing circuit is maintained.

95 (Reserved for special application.)

96 (Reserved for special application.)

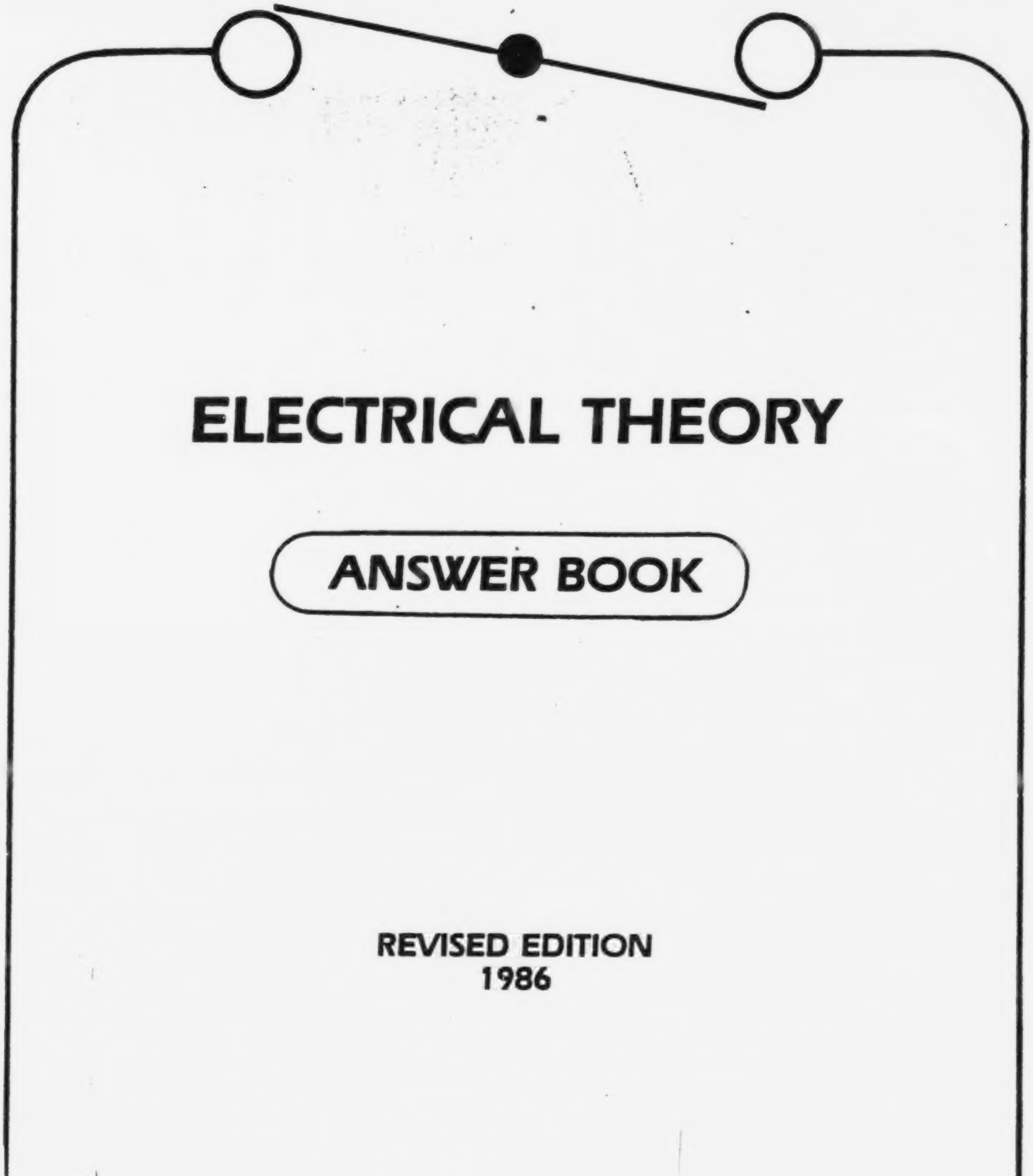
97 (Reserved for special application.)

98 (Reserved for special application.)

99 (Reserved for special application.)

The above numbers are used to designate device functions on all types of manual and automatic switchgear.

OR 8513305



ELECTRICAL THEORY

ANSWER BOOK

REVISED EDITION
1986

#12 ITP

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It is the policy of the Oregon Department of Education that no person be subjected to discrimination on the basis of race, national origin, religion, sex, handicap or marital status in any program, service or activity for which the Oregon Department of Education is responsible.

Lesson 1-1-1

THE ELECTRON THEORY SIMPLIFIED

Check-up: (1-1-1)

1. **What is an electron? Proton? Neutron? Nucleus? Atom? Molecule?**
   Electron is the very small negatively charged particle which circles the nucleus. All electrons are alike. The proton is stuck down in the nucleus of the atom and has a positive charge. The neutron is neutrally charged and is also located in the nucleus. The nucleus is the center portion of the atom. The atom is the smallest particle that can be divided and still retain molecules combining two or more atoms.

2. **How do "bound" electrons differ from "free" electrons?**
   Bound electrons are in the inner orbits of the atom and cannot be easily forced out of their orbits.

3. **Why is the electron theory important to you with regard to your future work in the electrical field?**
   According to the electron theory all matter is made up of atoms. The electron theory is the basis of the entire study of electricity and has led to many important discoveries in electronics, physics and atomic physics.

4. **Basically, all matter is what, according to the electron theory?**
   Matter is composed of atoms.

5. **Scientific fact proved beyond doubt is known as a "law." Is the electron theory a law?**
   No.

6. **According to the electron theory, what is an electric current?**
   The movement of free electrons.

7. In what way does a carbon atom differ from a hydrogen atom?

Hydrogen has only one electron revolving around its nucleus while carbon atom has six such electrons. Essentially, the difference between atoms of different elements is the number of electrons in orbit.

8. Approximately how many different kinds of atoms exist?

There are more than 96 natural elements or 96 plus different atoms and a number of man made materials.

9. What is a compound?

Compounds are substances produced by combinations of two or more different elements and have characteristics that are completely different from the elements that form them.

10. In an atom, what relationship exists between positive charges, which are called "protons," and negative charges, which are called "electrons"?

The negative charges equal the positive charges.

Check-up: (1-1-2)

1. What are some of the practical applications of the photoelectric cell?
Light meters, automatic door openers, sun switches.

2. Describe the basic wet cell. In what direction does the electrolyte carry the current inside the cell?
Lead and lead peroxide plates - H_2SO_4 *electrolyte.*
From the + terminal to the electrolyte to the - plates.

3. When two dissimilar metals are riveted or welded together for the purpose of converting heat into electricity, what is this called?
A thermocouple.

4. Give the most common use of the device in question 3.
Used as a heat indicating device such as a pyrometer.

5. When we apply pressure to a crystal of quartz we produce what is called piezoelectric electricity. What are some of the common uses for this particular type of electricity?
Crystal microphones, head phones, phonograph pickups.

6. In your own words, state the law that exists with: (a) unlike charges; (b) like charges.
(a) Unlike charges attract each other; (b) like charges repel each other.

7. When we rub certain materials with certain other materials we produce electricity. What is this electricity called?
Static electricity.

8. Describe the three methods by which the electrical charges in question 7 may be dissipated.
By connecting a conductor (wire, etc.) from one material to the other; by actual contact between the two materials; an arc between the two materials.

9. **Name one natural phenomenon which occurs due to the accumulation of static charges.**
Lightning

10. **What is the transfer of a charge from one material to another without actual contact called?**
Induction charge

Check-up: (1-1-3)

1. Find the sum of 131, 222, 21, and 413.
   * 787

2. Find the sum of 425, 36, 9, 215, 4, and 907.
   * 1,596

3. A pump operated 2 hours and 45 minutes to empty a tank filled with transformer oil. The meter reading showed that 4,200 gallons were removed during the first hour, 5,420 during the second hour, and 3,600 during the last 45 minutes. How mant gallons of oil did the tank contain originally?
   * 13,220 gallons

4. Four resistors, 100 ohms, 1,000 ohms, 39 ohms, and 470 ohms are connected in series. What is their total resistance?
   * 1,609 resistance

5. Using U.S. standard, the gage and thickness for sheet steel is as follows: No. 00-0.2656 inches; No. 4-0.234375 inches; No. 7-0.1875 inches ; No. 13-0.9375 inches; If one sheet of each of the gages of sheet steel were stacked together, find the approximate thickness of the stack.
   * 1.624975 inches

6. If an electric meter registers 7,968 watt-hours at one reading, and 10,430 watt-hours at the next reading, how many watt-hours were used by the customer?
   * 2,462 watt-hours

7. In the construction of one substation it was found that out of a stock of 1,037 pounds of conduit fittings there remained a quantity of 359 lbs. How many lbs. were used?
   * 678 lbs.

8. What is the total weight of copper in 649 transformers, if the amount of copper in each transformer weighs 37 lbs.
   * 24,013lbs.

9. A tank has a capacity of 5,130 gallons. How mant hours will it take to fill if oil is pumped in at the rate of 270 gallons per hour?
   * 19 hours

10. A 115 KV circuit breaker has a movable contact 7.895 inches long, but 0.725 inches of the contact has burned away. What lengthremains?
    * 7.17 inches

11. Nine equal distances of 4.75 inches are marked off a piece of heavy copper bus. What is the total distance marked off?
    * 42.75 inches

12. A piece of brass tubing 24.375 inches longis divided into equal parts measuring 1.625 inches in length. How many parts are there?
    * 15

13. A technician measured seven different resistors with its ohmeter as follows: 471 ohms, 500 ohms, 490 ohms, 452 ohms, 460 ohms, 420 ohms, and 485 ohms. What was the average balue of the seven reisistors?
    * 468.285

14. A steel beam expands 0.01 percent of its length when exposed to the sun. Find the increase in the length of a beam 25 feet 8 inches ong.
    * .0308 (.0001 x 308" = .0308)

15. Gage sheet copper #25 is 0.179 inch thick and wieghs o.811 pounds per square foot. Find the thickness of a pile of 48 such sheets.
    * 8.592 inches

16. From problem 15, find the weight of this number of sheets if each sheet has 6.25 square feet.
    * 243.3 lbs.

17. A brass rod was cut into 5 pieces of lengths; 4 1/4, 3 5/8, 6 1/2, 7 9/16, and 2 3/4 inches,.respectively. How long was the rod if 1 1/16 inch was wasted?
    * 25 3/4 inches

18. Find the difference between a pipe nipple 3 1/8 long and one 2 3/4 inches long.
    * 3/8 inch

19. What is the product when you multiply 2/3 by 5/7 ?
    * 10/21

20. In the blueprint of a substation control house, 1/4 inch in the print represents 1 foot in the actual house. Find the dimensions of the battery room that measures 2 1/2 by 4 1/8 inches.
    * 10 ft. x 16 1/2 ft.

Lesson 1-1-4

CURRENT FLOW—WHAT IS IT?

Check-up: (1-1-4)

1. What is current flow?
The movement of free electrons in the same direction along a conducting path.

2. What makes an atom release its "free" electrons?
The attraction of a positive charge.

3. According to the electron theory, in which direction does the current move: (a) external to a battery, (b) internally?
(a) From negative to positive battery terminals, (b) From the positive to the negative terminals.

4. Describe the action of "free" electrons in a wire when current starts to flow.
Free electrons start to move throughout the wire at the same time.

5. Are any of the "free" electrons lost as a result of current flow?
No.

6. What is the instrument used to measure current flow called?
An ammeter.

7. If we are passing a current at the rate of 1 coulomb per second: (a) What practical unit is used to measure the current that is flowing? (b) What does an instrument used to measure current actually measure according to the electron theory?
(a) Ampere; (b) It is measuring in amperes the number of electrons that are passing per second.

8. **How many amperes (a) in 1 milliampere; (b) in 1 microampere; (c) in 50 microamperes; and (d) in 40 milliamperes?**
(a) .001 ampere; (b) .000001 or 1×10^{-6} *ampere; (c) .000050 or* 5×10^{-5} *ampere (d) 0.040 ampere*

9. **Describe what is meant by "potential difference," "voltage," and "emf."**
The force between two unequal charges. The difference of potential between these two charges provides the electro-motive force (emf.) "Pressure" or voltage.

10. **What is the practical unit of electric potential? How many in 1 KV?**
The volt. 1 kv = 1,000 volts.

Lesson 1-1-5

USING FORMULA FOR PROBLEM SOLVING

Check-up: (1-1-5)

1. A tool box measures 2 feet 3 inches long, 18 inches wide and is 1 foot deep. What is the volume?
   5,832 cubic inches or 3.375 cubic feet.

2. What is the volume of a cylindrical oil tank 3 feet in diameter and 6 feet 6 inches high?
   $v=(\pi r^2)\ h\ =\ 45.9459$ *cubic feet or 79,394.5 cubic inches*

3. If 1 gallon = 231 cubic inches, what is the capacity of the above tank in gallons?
   343.699 gallons

4. How many cubic feet of cement are required for a retaining wall that is 20 feet long, 8 feet high and 2 feet thick?
   320 cubic feet, 11.85 yards

5. A forged steel shaft for a generator is 18 inches in diameter and 10 feet long. If forged steel weighs 0.283 pounds per cubic inch what is the weight of the shaft?
   30,536.35 cubic inch; weighs 8,641.79 lbs.

6. What is the distance across the corners of a square nut that is 2 3/8 in. on a side?
   distance = 3.35875 inches

7. An 8 foot high, chain link fence is to be installed around the perimeter of a distribution substation. The area to be enclosed measures 180 ft. x 125 ft. How many square feet of fencing will be required?
   4,880 square feet

8. A man's height is 174 cm. What is his height in feet and inches?
5' - 8 1/2" height

9. What is the diameter in inches of the bore of a 75 mm gun?
2.95275 inch

10. A pipe used as a conduit for electric wires has an inside measurement of 2.17 inches and an outside measurement of 2.39 inches. How thick is the pipe?
0.110 inches thick

11. A flat copper bar to be used behind a switchboard is required to be exactly .500 inch wide. When measured by micrometer caliper the width is found to be .499 inch. How much too small is it?
1/1000 inch or .001 inch

12. In an induction motor the rotating part which is called the rotor is surrounded by a stationary part called the stator. In order that the rotor may revolve freely the hole in the stator must be somewhat larger than the rotor. This leaves what is known as an air-gap between the rotor and stator. If the hole in the stator is 24.375 inch in diameter and the diameter of the rotor is 24 inches, what is the width of the air gap?
0.1875 inch air gap

13. A microwave antenna tower is held in position by three guy wires that reach the ground 49 ft. from the foot of the tower. Find the length of the guy wires if they are fastened to the tower 70 ft. from the ground.
85.445889 ft.

14. A circuit breaker that is equipped with a pneumatic operator, air-compressor and control system has a normal operating pressure of 225 p.s.i. For closing the breaker, air is admitted to the mechanism cylinder by an electrically operated control valve. If the closing piston had a 3 inch diameter, what force would be exerted to close the circuit breaker?
1,590.44 lbs.

Lesson 1-1-6

MAGNETIC FIELDS

Check-up: (1-1-6)

1. Remembering that the left-hand rule is based on the electron theory that current flow is from the negative to the positive terminals, state the left-hand rule for:

   a. A conductor carrying current-- *grasp with the left hand, thumb pointing in the direction of electron flow, the fingers when wrapped around the conductor will point in the direction of the magnetic lines of force.*

   b. A coil of wire carrying current-*if the fingers of the left hand are wrapped around a coil in the direction of current flow, the thumb will point toward the north pole.*

2. If you suspend a coil of wire by a thread so that it can move freely, what happens when you pass a current through it? What does this prove?
The coil will assume a north south position. This proves that a coil carrying current through it exibits the propertys of a magnet.

3. In what two ways can you increase the strength of magnetism in a coil carrying current?
Increase the number of turns or increase the strength of the current.

4. In what way can you further increase the flux density and therefore increase the magnetism of the coil? Why is this so?
By inserting an iron core in the coil. Because the iron core offers much less reluctance to lines of force then does air.

5. What do you use to determine the direction of a magnetic field around a current-carrying conductor and how can you verify the results?
Use a compass needle. Verify results by applying the left-hand rule. The north seeking pole of a compass is really a south pole on the needle.

6. How can you show the pattern of the lines of force around a permanent magnet or around a coil of wire carrying current?
By using iron filings.

7. How can you verify the assumption that the magnetic lines of force travel from a north pole to a south pole?
By using a compass needle.

8. What sort of a pattern of magnetic field exists around a straight conductor carrying current?
Concentric circles.

9. A horseshoe magnet consists of a horseshoe-shaped piece of iron with a coil of wire wound around each end. The coils are wound in the same direction. What will happen if the direction of one of these coils is reversed and current is passed through the coils?
The fields will tend to cancel each other and you may not have a magnet field at all.

10. Do lines of force ever cross or unite with each other?
They do not cross, but they seem to unite or crowd together.

11. Where is the magnetism of a magnet concentrated?
In the poles or at the ends of the magnet.

12. Why is it important to handle watt-hour meters carefully?
They are not only a delicate instrument, but a sharp blow may weaken the permanent magnet.

13. State the law that applies to like and unlike poles of a magnet.
Like poles repel each other; unlike poles attract each other.

14. Why do lines of force travel easier through iron than through air?
Because air has a greater reluctance than iron.

15. How do we shield an instrument from the flux lines of a magnetic field?
By enclosing the instrument in a soft iron shield (box or similar container).

16. **What polarity does a piece of iron assume when placed in a magnetic field?**
The polarity is always north to south. The north pole is assumed to point in the direction that the lines of force are traveling.

17. **When a piece of magnetic material has all of the lines of force that it will hold, what do we say about it?**
The piece of iron is said to be saturated.

18. **Is there any material that magnetic lines of force will not pass through?**
No. Magnetic lines of force will pass through any material known.

19. **What is a solenoid coil?**
A helically wound coil that is made to produce a strong magnetic field is called a solenoid.

20. **What is the difference between a fuse and a magnetic circuit breaker?**
The circuit breaker is used to protect circuits against short circuits or overload just like a fuse. A fuse burns open and can not be reused, a circuit breaker will trip, but can be reset and used again.

Lesson 1-1-7

WHAT CAUSES CURRENT FLOW

Check-up: (1-1-7)

1. Of the six different sources of electricity, which ones are used most frequently to supply voltage for the use of electric power?
Chemical action and magnetism.

2. What are the three basic elements of an electrical circuit?
A power source, connecting wires or conductors and some device that uses the energy called a load (voltage--resistor--current.)

3. State the conditions necessary to have current flow in a circuit.
A complete circuit. A voltage source, conductors providing a complete path for current to flow.

4. Can voltage exist without a complete electrical circuit?
Yes

5. What effect does voltage have in controlling current in a circuit?
The polarity of the voltage source determines in which direction current flows in a circuit and the amount of voltage supplied determines how much current will flow. For a fixed amount of resistance--a higher voltage will cause more current to flow or lower voltage, less current.

Check-up: (1-1-8)

1. Does every substance possess resistance to the flow of electric current?

   Yes

2. Would you use glass as a conductor of electricity? State the reason for your answer.

   No. Glass has too much resistance and is considered an insulating substance.

3. A copper conductor having a diameter of 128.5 mils has a resistance of 0.64505 ohms per 1,000 feet. What resistance would it have if it had a diameter of 460 mils?

   $$R_2 = \frac{R_1 D_1^2}{D_2^2} = \frac{0.64505(128.5)^2}{(460)^2}$$

   $$R_2 = 0.0504\,\Omega/1000 \text{ feet}$$

4. What are materials having a very low resistance called? What is the name given to materials having a very high resistance?

   Materials having low resistance are called conductors, high resistance are called insulators.

5. No. 18 copper magnet wire has a resistance of 34.3728 ohms per mile. What is the resistance of 1,000 feet of this wire?

   $$R_2 = \frac{R_1 L_2}{L_1} = \frac{34.3728\ (1000)}{5280}$$

   $$R_2 = 6.510\,\Omega/1000 \text{ feet}$$

6. The resistance of a copper wire, at zero degrees centigrade, is 12.5 ohms. What will the resistance of this wire be at 45 degrees centigrade?

   14.90 Ω

7. The resistance of a copper wire, at 20 degrees centigrade, is 6 ohms. What will the resistance of this wire be at 30 degrees centigrade?

   6.2358 Ω

8. **Silver has a resistivity of 1.628 microhn-cm. Is it a better or poorer conductor of electricity than copper? Why?**

   Better--Silver has less resistance.

9. **Porcelain has a very high resistivity at ordinary temperatures. Will this material make a good insulator?**

   Yes, porcelain makes a good insulator.

10. **Iron has a resistivity of 9.96×10^{-6} ohm-cm. Will iron make as good a conductor of electricity as aluminum? Please give the reason for your answer.**

    No. The resistivity of aluminum is only 2.828×10^{-6} *ohm-cm.*

11. **How do you tell the values of resistors?**

    By measurement; by printed label; by color code.

12. **What is an ohm?**

    The unit of measurement of resistance. 1 ohm will allow 1 amp to flow when 1 volt is applied across it.

13. **In terms of ohms, how much resistance is one megohm? One microhm? One kilohm? One milliohm?**

    1 megohm = 1,000 $K\Omega$ *or 1,000,000 1 microhm =* $1 \times 10^{-6}\Omega$ *or 0.000001*

    1 kilohm = 1,000 1 milliohm = $0.001\ \Omega$ *or* 1×10^{-3}

14. **What is a rheostat? A potentiometer?**

    A rheostat is a two terminal variable resistor used to control current. A potentiometer is a three terminal variable resistor used to control current also, but provides a voltage divider function.

15. **What is meant by the tolerance of a resistor?**

    Resistors may deviate a given percent from their assigned value. The tolerance is the % by which the resistor deviates.

Lesson 1-1-9

ALGEBRA REVIEW

Check-up: (1-1-9)

Addition: Find the sum of:

1. 37, −67, 96, 105, −3 = ? *168*

2. $a^2 -2ab +b^2$ = ? $a^2 -2ab +b^2$

3. $3x -5y -8$
$\underline{3x +5y -8}$
$6x \quad -16$

4. $6x -7a$, $4a$, $4x +10a +17$ = ?
$10x +7a +17$

5. $3x +y$, $7x -2y$, $5x +4y$ = ?
$15x +3y$

6. $-3ax$, $14ax$, $-25ax$, $19b$, $16ax$ = ?
$2ax +19b$

Subtraction:

7. From $6xy -13h$ take $10xy -4k$ = $-4xy -13h +4k$

8. From $a^2 +2ab +b^2$ take $a^2 -2ab +b^2$ = $4ab$

9. From the sum of $3a^2 -2ab +b^2$ and $4a^2 -5ab -b^2$ take $4a^2 -5ab -7b^2$ =
$3a^2 -2ab +7b^2$

10. From $8x^2 -10y^3 +11z^3 -12xyz$ take $-13x^2 +14y^3 -15z^3$ =
Solution: Change the sign and add
$8x^2 -10y^3 +11z^3 -12xyz$
$+ \quad - \quad -$
$\underline{(-)13x^2 \ (+)14y^3 \ (-)15\ z^3}$
$21x^2 -24y^3 +26z^3 -12xyz$

Multiply:

11. $(x^3)\ (x^4) = ?\quad x^7$ 12. $(a^2)\ (a^3)\ (-a^4) = ?\quad -a^9$

13. $(3a^2)\ (4b) = ?\quad 12a^2b$ 14. $(4x + 7z)\ (6R) = ?\quad 24xR + 42Rz$

15. $(7ax^3 - 21ab^4 - 3x^2)\ (2a^2b^3x^4) = ?\quad 14a^3b^3x^7 - 42a^3b^7x^4 - 6a^2b^3x^6$

16. $(A + 1)^2 = ?\quad A^2 + 2A + 1$ 17. $(X + 6)\ (X + 7) = ?\quad X^2 + 13X + 42$

18. $2a + 5b - (a + 4b) = ?\quad a + b$ 19. $10y - 10 - (-3y + 4) = ?\quad 13y - 14$

20. $a - [b - (a + 4)] = ?\quad 2a - b + 4$ 21. $m - (3m - 2 + p) - m - 1 + p = ?\quad -3m - 1$

22. $X - 2y + 3z - (2x - 3y + 4z) - (-3x + z) = ?\quad 2X + y - 2z$

23. $17 - [2 + (3 - 7)] = ?\quad 19$

24. $2X - [3X - (X - Y) - Y] = ?\quad 0$

25. $19 - 3 - [4 - (-6 + 10)] = ?\quad 16$

Divide:

26. $12X^3y$ by $6Xy = \quad 2X^2$ 27. $-18ab^3$ by $6ab^2 = \quad -3b$

28. $\dfrac{16a^3b^4}{-4ab^2} = ?\quad -4a^2b^2$ 29. $\dfrac{x^2 + 7x + 12}{x + 3} = ?\quad x + 4$

30. $\dfrac{x^2 + 9x + 14}{x + 7} = ?\quad x + 2$

Lesson 1-1-10

EQUATIONS

Check-up: (1-1-10)

Solve for the value of x in the following equations.

1. $5x - 8 = 2x + 7$
   $x = 5$

2. $8x + 3 = 3x + 13$
   $x = 2$

3. $4x + 3 [2x - 4 (x-2)] = 72 - 6x$
   $x = 12$

4. $6x + 8 - 23x = 16x - 3$
   $x = 11/33$ or $1/3$ or 0.333

5. $7 (2x - 6) - 8 = 10x + 10$
   $x = 15$

6. $2x - 3 = 3x - 7$
   $x = 4$

7. $4x - 10 = 2x + 2$
   $x = 6$

8. $300x - 250 = 50x + 750$
   $x = 4$

9. $2.5x + 0.5 = 1.5x + 1.5$
   $x = 1$

10. $4(4x - 6) + 2(2x - 3) = 5(2x - 6) - 10$
    $x = -1$ (minus one)

Solve for the unknown.

11. $16 - (2y - 3) = 2y + 3$
    $y = 4$

12. $10-(E - 2) - E = -27 + (E+3)$
    $E = 12$

If F stands for number of degrees Fahrenheit scale and C for the number of degrees centigrade:

$$C = \frac{5}{9} (F - 32) \quad \text{And} \quad F = \frac{9}{5} C + 32$$

13. $176°F = ?$ in C
    $C = 80.0°$

14. $24°c = ?$ in F
    $75.2°$ F

15. $55° C = ?$ F
    $131°F$

Lesson 1-1-11

PROBLEMS INVOLVING RESISTANCE AND WIRE SIZES

Check-up: (1-1-11)

1. In wire measure, (a) what is a mil? (b) what is a circular mil? (c) what is a milfoot?
   (a) A mil is 1/1000 inch (b) A circular mil is a measure of area (cross section of a round wire) that is 1/1000 inch in diameter; $cm = d^2$ *(when the diameter is in mil) (c) A milfoot is a wire 1/1000 inch in diameter and one foot long.*

2. What is the circular mil area of a wire 0.289 inch in diameter?
   $cm = (289)^2 = \underline{83{,}521}$ *circular mil*

3. What is the diameter of a wire containing 1,024 circular mils?
   $d = \sqrt{cm}$ $\quad d = 32$ *mil* *or* $\underline{0.032 \text{ inch}}$

4. What is the diameter of a wire containing 83,690 circular mils?
   $d = \sqrt{cm}$ $\quad \underline{0.289 \text{ inch}}$

5. What area in circular mils will a circle having an area of 2.65 square inch have?
   3,375,671

6. A rectangular bus bar 1/4 inch thick by 4 inches wide would have how many circular mil?
   $$c.m. = \frac{\text{sq. mil}}{0.7854} = \frac{1{,}000{,}000}{0.7854} = \underline{1{,}273{,}237 \text{ c.m.}}$$

7. What is the resistance of 10 miles of copper wire 1/2 inch in diameter?
   $c.m. = d^2 = (500)^2 = 250{,}000$ *c.m.* $\quad 2.197\,\Omega$

259

8. What size wire (B & S) will have a resistance of practically one ohm per 1,000 feet?
# 10 wire gage

9. What wire, American guage, should be used to transmit electric power 2 miles (2 miles out and 2 miles back); resistance should not exceed 2.7 ohms, temperature at twenty degrees c.?
Wire gage #1 #1 has .126 Ω /1000 ft. (from table)

10. How many miles of No. 00 wire will it take to make 8 ohms?
No. 00 has .0795 Ω /1,000 ft. 19.059 miles

11. What is the resistance of 500 ft. of No. 14 copper wire at 25 degrees centigrade?
1.29 Ω

12. What size wire will have a resistance of practically one ohm per 1,000 feet?
No. 10 wire gage B & S

13. A relay has a coil that measures 150 ohms resistance. The coil has 750 turns of about 6 inches in average length. What size wire is the coil wound with?
No. 36 wire gage

14. What size will an aluminum wire be which has the same resistance as a No. 4 copper wire?

Hint: $R = \frac{K \times L}{C.M.}$ Where K is the ohms resistance of one mil-foot of the kind of wire used, L is the length of the wire in feet, and C.M. is the area of the wire.

Note: The ohm/mil-ft of aluminum is = 17

No. 2 wire gage or 67,193 c.m.

15. Find the resistance of 1,000 ft. of No. 4 aluminum wire.
0.407 Ω

16. No. 8 copper wire has a resistance of 0.641 ohm per 1,000 ft. What is the resistance of two miles of this wire?
6.768 Ω

17. A square conductor that is 0.50 inch on a side has a resistance of 0.004 ohm. Another square conductor that is 0.25 inch on a side is of the same material and the same length. What is the resistance of the second conductor?
0.016 Ω

18. The resistance of a power line wire constructed from No.0000 aluminum was measured and found to be 0.96 ohms. If No. 0000 aluminum has a resistance of 0.0804 ohm/1,000 ft., find the length of the wire.

$$\frac{R_1}{R_2} = \frac{A_2}{A_1}$$

11,940 ft. long or 2.26 miles

19. No. 2 copper wire, which has a diameter of 0.258 in., has a resistance of 0.840 ohm/mile. What is the resistance of 800 ft. of No. 6 wire, which has a diameter of 0.162 inch?

$$\frac{R_1}{R_2} = \frac{(d_2)^2}{(d_1)^2}$$

0.3224 Ω

20. It is desired to install a conductor to carry 40 amperes. What size copper wire should be used?
No. 8 wire gage

Instructor's Note: Emphasize that c.m. is a measure of cross sectional area the same sort of thing as a square foot or an acre of land, etc. Note that a circle which represents the end of .002" in diameter would contain 4 cir mil or 4 times as much area as a circle .001" in diameter.

Square Mil = c.m. x 0.7854

$$\text{Cir Mil} = \frac{\text{Square Mil}}{0.7854}$$

For aluminum conductors the allowable current-carrying capacities shall be taken as 84% of those given in the table for the respective sizes of copper conductors with the same kind of insulation.

Lesson 1-1-12

PROBLEMS INVOLVING RESISTANCE AND TEMPERATURE

Check-up: (1-1-12)

1. The field-magnet winding of a 230 volt d-c generator has a resistance of 34.0 ohms at 20 degrees c. Find the resistance of the winding, which is copper, when the temperature rises to 55 degrees c.
   38.68°c

2. The resistance of the secondary of a transformer was 2.50 ohm at 20 degrees c. After the transformer had operated under full load for 6 hours, the resistance of the secondary was measured and found to be 2.99 ohm. What was the final operating temperature?
   69.8°c

3. The resistance of a copper wire is 6.4 ohm at 10 degrees c. What is it at 75 degrees c.?
   8.10 Ω

4. The cold (20 degrees c.) resistance of an armature was 3.64 ohm. The hot resistance was 4.86 ohm. What was the temperature rise?
   t_2 *= 105.2° temperature or a rise of 85.2°c.*

5. How does the increase of temperature affect the resistance of all pure metals?
   Increase in temperature - increase in resistance.

6. What is the length of a 250 lb. coil of No. 12 wire?
   12,626 feet

7. What is the temperature coefficient of resistance?
   The amount that the resistance is affected. Each degree of temperature change is called the temperature coefficient. The resistances of all materials change at a nearly uniform rate for a specific material.

8. The primary coils of a transformer having a resistance of 5.48 ohm at 30 degrees c.After a run of 4 hours, the resistance has risen to 6.32 ohms. What is the temperature rise of the coil?
$t_2 = 70.5°c$. or a temperature rise of 40.5°c.

9. Certain substances, notably carbon, porcelain, glass, certain semi-conductors such as germanium and metal oxides, decrease in resistance very rapidly when heated. Their temperature coefficient is said to be what? (positive or negative)
Negative

10. Alloys with zero temperature coefficients can be compounded. That is, the resistance of conductors composed of these alloys remain practically constant at all ordinary temperatures. Their temperature coefficients are 0.0. Judging from what you have learned from this lesson, do you think such an alloy would make a good remote temperature detector?
No

STUDY HELP QUESTIONS

1. **The old fashioned string of Christmas tree lights would fail to burn if any one of the bulbs were faulty. Why is this so?**
   Because the lightbulbs are connected in a series string and the failure of one bulb opens the string and interrupts the flow of electrons.

2. **Can you explain why the resistance of a series circuit is equal to the sum of the individual resistances?**
   The resistance of any given price of wire has a fixed value of resistance per foot. Two feet connected end to end would increase the total resistance of the additional foot. Therefore, resistors connected end to end, in series add and the sum of the individual resistors equals the total.

3. **What is a "short" circuit? What are some of the common causes?**
   A short circuit means that wires from the voltage source are contacting each other, or a conductor is connected across a load such as a resistor. Causes: Poor insulation, equipment failure.

4. **What is an "open" circuit? A "closed" circuit? What are some of the devices and methods used when it is desirable to open and close circuits? What are some of the causes that open a circuit when it is not desirable?**
   In an open circuit the electrical pathway is broken (open) and current can not flow. In a closed circuit there is a path for current to flow. A fuse or switch is used to open the circuit. A blown fuse, broken conductor.

5. **How is Ohm's law applied to d-c series circuits?**
   $I = \frac{E}{R}$ $R = \frac{E}{I}$ $E = IR$

6. **Why is the current in all parts of a series circuit the same?**
   There is but one conducting path for current to flow in a series circuit; therefore the same current flows in all parts of the circuit.

7. **Why is the commercial use of series circuits limited?**

The failure of any device (open circuits) interupts the power to all other devices in the circuit.

Lesson 1-2-1

OHM'S LAW AND SERIES CIRCUITS

Check-up: (1-2-1)

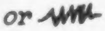
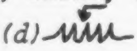
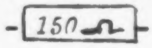
1. **What constitutes an electric circuit?**
   An electrical pathway for current flow, including the conductor and the voltage source.

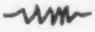
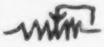
2. **Explain in your own words the difference between an "open" and "closed" circuit.**
   In an open circuit the electrical pathway is broken and current cannot flow. In a closed circuit the electrical pathway is complete through the conductor and current can flow.

3. **What is the primary function of a switch in an electric circuit?**
   To open and close a circuit or a part of a part of a circuit to permit current to flow or prevent current from flowing.

4. **State Ohm's Law. What are the three ways this law may be written?**
   The current flowing in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance.
   $I = E/R$ $E = IR$ $R = E/I$

5. **What are the units of the following and define each:**
   a. **Electromotive force (E)**
   b. **Current (I)**
   c. **Resistance (R or Ω)?**
   a. *Volt - the emf required to cause 1 amp to flow through 1 ohm.*
   b. *Ampere - the amount of current that will flow through a resistance of 1 ohm when 1 volt emf is applied to it.*
   c. *OHM - the amount of resistance which will allow 1 ampere to flow when 1 volt is applied across it.*

6. What symbols do we use for the following: (a) amperes, (b) volts, (c) ohms, (d) potentiometer, (e) watts, (f) fixed resistor, (g) rhoestat.
(a) I (b) E (c) R or  *(d)*  *(e) P or W (f)* 

or  *(g)* 

7. Of what does a series circuit consist?
A circuit in which all resistors or loads are connected end to end or in series, so current flowing would flow from one load to the next, to the next, and etc.

8. What is the total resistance, R_1, or R_1, R_2, R_3, and R_4 connected in series?
$R_t = R_1 + R_2 + R_3 + R_4$

9. How does the voltage divide among the various resistors connected in a series circuit?
The voltage across each resistor is only a part of the total voltage and is a function of the value of the resistor and the current flowing through the resistor. The sum of the voltages across each resistor always equals the total applied voltage.

10. In a series circuit what is the value of the current in any part of the circuit in terms of the total current?
The current is the same in any part of a series circuit. The total current flows in all parts of the circuit.

11. What is meant by "voltage drop"?
When the voltage moves current through a resistor the force is expended (the pressure [EMF] is lowered). This loss of EMF is called "voltage drop." It is a difference in potential from one part of a circuit to another.

12. What constitutes a "short circuit"?
A short circuit means that the wires from the voltage source are contacting each other, or a wire connected across resistor, or somewhere in the circuit two bare wires are in contact providing another path for current to flow.

13. **How do series power sources affect current?**
When power sources are connected in series with the correct polarity they will provide more voltage. When power sources are connected in parallel they will provide more current (amperes or ampere hours).

14. **What are some of the causes of an "open circuit"? How can you find where the circuit is open?**
Loose connections, burned out resistors or lamp filaments, broken wires, poor contacts in a switch, blown fuses - Many other causes could be listed. Find the place where the circuit is open by means of a voltmeter--an ohmeter, a small buzzer and battery, a test lamp to name a few (others could be listed).

Lesson 1-2-2

THE MATHEMATICS OF D-C SERIES CIRCUITS

Check-up: (1-2-2)

1. How much resistance does a resistor have if 1 ampere flows through it when 10 volts are applied across it? Show your work.
   10 ohms

2. What amount of current will flow if you apply 100 volts to a 100-ohm resistor?
   1 ampere

3. A voltmeter across a resistor reads 50 volts and an ammeter in series with the resistor reads 1.5 amperes. What is the value of the resistor?
   33 1/3 ohm

4. What voltage is necessary to force 2 amperes through a 20-ohm resistor?
   40 volts

5. An electric iron draws 5 amperes from a 120-volt line. What is the resistance of the iron?
   24 ohms

6. A current of 1 milliampere flows through a 2,000-ohm resistor. What is the voltage applied to the resistor?
   2 volts

7. What is the voltage across a resistance of 1 megohm when 2 milliamperes flow through it?
   2,000 volts

8. A buzzer requires 150 milliamperes at 1.5 volts to operate it. How much resistance does it have?
   10 ohms

9. If a 1-milliampere maximum-rated milliammeter having a resistance of 27 ohms is connected across a 12-volt battery, how much current will it draw? What will happen to the milliammeter?
0.444 amps, will burn out.

10. If a 1-ampere maximum-rated ammeter having a resistance of 79 milliohms in series is connected with a load consisting of 12 ohms, and a voltage of 120 volts is applied across the 12-ohm load and the ammeter, what will happen to the ammeter? How much current will it draw?
9.93 amperes - probably damage the meter.

11. From the disastrous results obtained in problems 9 and 10, what is your general conclusion regarding the use of ammeters? How should they always be connected in a circuit? Should the resistance of the load be checked before applying the ammeter to the circuit? If so, why?
Ammeters should always be connected in series with the load to be measured, in order to calculate the approximate current scale to use.

12. If a voltmeter having a resistance of 1940 ohm is connected in series with a load consisting of 60 ohm and requiring 120 volts to operate it, what will be the result?
Voltage across the load of 60 Ω will be 3.6 volts. Since the load requires 120 volts, the load will not operate satisfacturly.

13. From the results obtained in problem 12, what are your conclusions about how a voltmeter should be connected in a circuit?
Voltmeters should be connected in parallel with the load.

14. Given three resistors of 2 ohms, 5 ohms, and 10 ohms, respectively, connected in series, what is the total resistance of this combination?
17 Ω

15. Eight lamps, 30 ohm each, are connected in series and 120 volts is applied to this series circuit. (a) What current flows through each lamp? (b) What voltage would appear across each lamp?
(a) 1/2 amp (b) 15 volts

16. Two wires lead from a pole to a house. The resistance of each wire is 0.35 ohm. When the current is 50 amp and the voltage between wires at the pole is 124 volts (a) How much voltage drop is there in the line (both wires combined?) (b) What is the voltage between the wires at the house?
(a) 35.0 volts (b) 89 volts

17. If the current is only 10 amp in the same line described in question 16; (a) How much voltage drop in the line? (b) What is the voltage between the wires at the house?
(a) 7 volt (b) 117 volts

18. A 10 ohm resistor is connected in series with another resistor of (unknown resistance) to a 120 volt source. The voltage measured across the 10 ohm resistor is 48 volts. (a) How much current flows in each resistor? (b) Find the resistance of the second resistor?
(a) 4.8 amps (b) 15 ohms

19. A switch board lamp requires 400 ma to make it glow. The hot resistance is 312 ohms. What pressure is required?
124.8 volts

20. An electromagnet has a resistance of 65 ohms. It will lift a certain load of iron when the current through it is 5 amp, but will not drop the load until the current is reduced to 3.5 amp. What voltage is required; (a) to lift, and (b) to release the load?
(a) 325 volts (b) 2275 volts

STUDY HELP QUESTIONS

1. **How does a parallel circuit differ from a series circuit?**
   A parallel circuit has more than one path through which current can flow.

2. **In a parallel circuit why is the voltage rating the same when applied to each resistance and when connected across a voltage source?**
   The voltage across each parallel leg is the same as the source because each of the legs is connected to the same voltage source.

3. **Why does current flow divide unequally in different types of electrical equipment connected in parallel?**
   Current will divide unequally as the load is different. The resistance determining how much current will pass with the applied voltage.

4. **How do you determine the total resistance of equal resistances connected in parallell?**

   $$\frac{\text{Resistance of one of the resistors}}{\text{Number of resistors connected in parallel}}$$ *(By dividing)*

5. **How do you determine the total resistance when unequal resistances are connected in parallel?**
   By formula $R_t = \frac{R_1R_2}{R_1+R_2}$ *or* $\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ *or* $R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$

6. **Why is a knowledge of algebra so helpful in acquiring an understanding of electric circuit problems?**
   Most circuit problems can be stated as a algeraic equation -- An understanding of algebra aids in finding the solution.

Lesson 1-2-3

ELECTRIC POWER—RATE OF DOING WORK

Check-up: (1-2-3)

1. Define "power" and give its symbol.
   The rate of doing work. Either "P" or "W"

2. What is the basic unit of power? What does this unit equal in terms of voltage and current?
   The watt equals 1 volt times 1 amp.

3. Give the two variations of the power formula, using Ohm's Law.
   $P = EI$ & $E = IR \therefore P = (IR)(I)$ or I_2R Also $I = \frac{E}{R} \therefore P = (E)\frac{(E)}{R}$ or $\frac{E^2}{R}$

4. Why are appliances, such as lamps, irons, soldering irons, and resistors, rated in watts?
   Watts indicate the rate at which electrical energy is changed into another form of energy, such as light or heat.

5. If two resistors, one having a resistance of 18 ohms and the other having a resistance of 7 ohms, are connected in series, and a voltage of 15 volts is applied to the circuit: (a) how much power is being used in each resistor; (b) what is the total wattage being used?
   (a) P #1 = 6.48 watts P #2 = 2.52 watts (b) Total P = 9 watts

6. The 7-ohm resistor in problem 5 is a 10-watt unit and the 18Ω resistor is rated at 2 watts. What will happen to the resistors in this problem?
   The 18Ω resistor will overheat and probably burn out. The 7 resistor will carry the load as it is rated at 10 watts.

7 746 watts ~~equal~~ one horsepower and this is often used in the rating of an electric motor. What would the rating in kilowatts be if a motor is rated at 50 HP?
   37.3 KW

8. **The resistance of a 600-volt voltmeter is 69,120 ohms. What amount of power is used when the voltmeter is connected across 480 volts? Show how you would check this.**

$$P = \frac{E^2}{R} = \frac{480 \times 480}{69.120} = 3.33 \text{ watts}$$

9. **What is the rating in horsepower of a motor which draws 46.625 amperes from the line at 480 volts. Expressed in kilowatts, what is the rating of this motor?**

Note: 1 HP = 746 watts HP of motor = 30 HP and 22.38 KW

10. **What is a fuse? How is it used?**

A fuse is a resistor of low resistance value and with a low temperature melting point. It is designed to open an electric circuit if the current through the resistor exceeds the fuse rating.

Lesson 1-2-4

D-C PARALLEL CIRCUITS

Check-up: (1-2-4)

1. Is the total resistance of two resistors connected in parallel more or less than the value of the smallest resistor?
   Less

2. Explain how the current flows in a circuit having two unequal resistances connected in parallel. Two equal resistances.
   The lesser valve of resistance will take more current--two equal resistances the current will divide equally.

3. If we have N number of resistors of equal value connected in parallel, how do we find the total resistance of the circuit?

   $$\frac{\textit{Resistance of one of the resistors}}{\textit{Number of resistors in parallel}}$$

4. What is the combined resistance of four 100-ohm resistors connected in parallel?
   25 ohm

5. What is the formula for finding the total resistance of two unequal resistors connected in parallel?

   $$R_t = \frac{R_1R_2}{R_1+R_2} \qquad \text{or} \qquad R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \qquad \text{or} \qquad \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

6. What does the voltage equal, in terms of the total voltage, across each resistor in the circuit when the various resistances are connected in parallel?
   The voltage across each resistor is equal to the total applied voltage and the same across each resistor
   or
   $E_T = E_1 + E_2 + E_3 +$ *etc., i.e., number of resistors.*

7. **What does the current equal, in terms of the total current, across each resistor in a circuit when the various resistances are connected in parallel?**

Each resistor of different value has a different current in it (through it). The sum of all these individual currents equals the total current or

$I_T = I_1 + I_2 + I_3$.

8. **Must all of the resistors connected in parallel in a circuit have the same voltage rating, such as an electric razor, a vacuum cleaner, a dryer, and a water heater?**

Yes

9. **You will remember the formula for finding the total resistance of a number of resistors connected in parallel:**

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} + \ldots \frac{1}{R_m}$$

From this formula please develop the formula for finding the total resistance of any number of resistors connected in parallel: R_t = ?

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \text{etc.}}$$

10. **Supply the missing words: In a parallel circuit, the same** *voltage* **is applied to each branch. The total current is equal to the sum of the** *current* **in the individual branches, and the effective resistance is equal to the applied** *voltage* **divided by the total** *resistance*; **it is always** *lower* **than the lowest resistance in the circuit.**

11. **A lamp is marked 125 volts and 200 watts. What current does it require?**

1.6 amp

12. What is the resistance of a 400-watt toaster which is made for use on a 120 volt circuit?
36 ohms

13. (a) Compare the power (watts) used by a 29 ohm heater when operated on a 240 volt line; and (b) when operated at one half voltage--i.e., on a 120 volt line.
240 volts P = 1,986.2 watts *Compared: When operating at 1/2 volts*
120 volts P = 496.55 watts *you reduce the power by 1/4.*

14. Four lamps of equal voltage and power rating are connected in series across a 440-volt line. The current through the lamps is 0.909 amp. (a) What is the power expended in each lamp? (b) How much is the resistance of each lamp when this amount of current is flowing?
(a) 99.99 watts (b) 121 ohm

15. (a) A 20,000 ohm resistor is rated 10 watts. What is the maximum current it can carry without exceeding its 10 watt rating? (b) What is the maximum voltage that could be dropped across this resistor without exceeding its 10 watt rating?
(a) 22.36 ma *(b) 447.2 volts*
$I = \sqrt{\frac{P}{R}}$ $E = \sqrt{PR}$

16. A 12 volt battery is charged at a 5-amp rate for 24 hours. How many KWH of energy is put into the battery?
1.44 k watt-hours

17. (a) A motor takes 5 amps on a 120 volt line. Find the horsepower output. (b) Find the KWH of energy consumed if this motor runs continuously for 24 hours. (c) Find the cost of operating the motor if energy costs 2 cents per KWH. Note: 746 watt equals 1 hp.
(a) h.p. = 0.804 *(b) 14.4 kwh* *(c) 28.8 cents or rounded off 29 cents*

18. A 120 volt power supply is connected to three resistors connected in series. The 1st resistor is 5 ohm. An ammeter indicates 6.2 amp of current flowing in this series circuit. If the voltage across the 3rd resistor is 62 volts; (a) What is the value of R_2? (b) How much power is expended in the circuit?

(a) $R_2 = 4.35$ *ohm* *(b) 744 watts*

19. In one test on heating a house by electricity it was found that it required 3.6 KWH per year to heat one cubic foot of space. At 1 1/2 cents per KWH, what would it cost to heat a house containing 12,000 cubic feet?

$648.00

20. If a 1000 ohm-10 watt resistor is connected across a 120 volt source, would the resistor overheat? Show why.

Yes $P = E^2/R = \frac{120^2}{1000} = 14.4$ *watts*

This represents 144% of its capacity.

Lesson 1-2-5

OHM'S LAW APPLIED TO PARALLEL CIRCUITS

Check-up: (1-2-5)

1. What is the combined resistance of 15 ohms, 10 ohms, and 5 ohms connected in parallel?

   $Rt = 2.727$ ohms

2. Four 5-ohm resistors are connected in parallel in a circuit having 5 volts impressed across it. (a) What is the total resistance? (b) How much current will flow in each resistor? (c) What is the total current in the circuit?

   (a) 1.25 (b) 1 amp (c) 4 amps

3. What is the combined resistance of 5, 10, 20 and 15 ohms connected in parallel?

   2.399 ohms

4. What is the combined resistance of: (a) three 50-ohm resistors in parallel; (b) four 50-ohm resistors in parallel; (c) five 50-ohm resistors in parallel?

   (a) 16 2/3 ohm (b) 12.5 ohms (c) 10 ohms

5. What is the combined resistance of 125, 250, 500, and 1000 ohms connected in parallel?

   66 2/3 ohms

6. We have two resistors connected in parallel: their values are 10 ohms and 15 ohms. If we cut the total resistance in half, what value of resistance will the third resistor have? How much current will flow in each resistor when we apply 15 volts to the arrangement?

   $R_3 = 6$ ohms

   $I_1 = 1.5$ amp $I_2 = 1.0$ amp $I_3 = 2.5$ amp

7. If 90 volts are applied to the circuit in problem 6:

(a) How much current will flow in each resistor when only the first two resistors are connected?

I_1 = 9 amps; I_2 = 6 amp

(b) How much total current will flow under these conditions?

15 amps

(c) How much current will flow in each resistor when we add the third resistor to the circuit?

I_1 = 9 amps I_2 = 6 amps I_3 = 15 amps

(d) How much total current will flow in the circuit with all three resistors connected in parallel?

I_t = 30 amps

8. How much power is being used in each of the three resistors under the conditions of problem 7?

P_1 = 810 watts; P_2 = 540 watts; P_3 = 1,350 watts

9. How much current will flow in each resistor in problem 1 when we apply 45 volts to the circuit? What is the total power being used in the circuit with 45 volts applied to it?

(a) I_1 = 3 amp; I_2 = 4.5 amps; I_3 = 9 amps
(b) 742.5 watts

10. In problem 1 we wish to cut the resistance down to a value of 1/3 that obtained with 15, 10, and 5 ohms. How much will the value of the fourth resistor be when connected in parallel with the other three resistors?

R_t = 2.727 ohms (from prob. 1)
Value of the fourth resistor = 1.3636 ohms

11. Three resistors are connected to a 120 volt line. Total current is 12 amps. One resistor is 20 ohms, one is 30 ohms. Calculate the ohms for the third resistor.

R_3 = 60 ohms

12. When a resistor of 80 ohms is connected in parallel with a resistor of 120 ohms; what is the total resistance?

48 ohms

13. Three resistors are in parallel; one is 250 ohms, one is 300 ohms, one is 150 ohms. The 250 ohm resistor has a current of 60 ma. Calculate the current in the other two resistors, and the total current in the line.

300 Resistor has 0.05 amp thru it

150 Resistor has 0.1 amp thru it

$I_t = 0.21$ *amp*

14. Find the total resistance of (a) two 1000 ohm resistors connected in parallel, (b) four 1000 ohm resistors connected in parallel.

(a) 500 ohms

(b) 250 ohms

15. A 4-ohm, 8-ohm, 12-ohm and 16-ohm resistor are connected in parallel. Calculate the combined resistance of this parallel group.

1.92 ohms

16. How much power would be expended in each of the parallel connected resistors in question 15 if this group is connected across a 120 volt source?

(Watt total = 7500 watts)

3600 watt @ 4Ω ; 1800 watts @ 8 Ω ; 1200 watts @ 12 Ω &

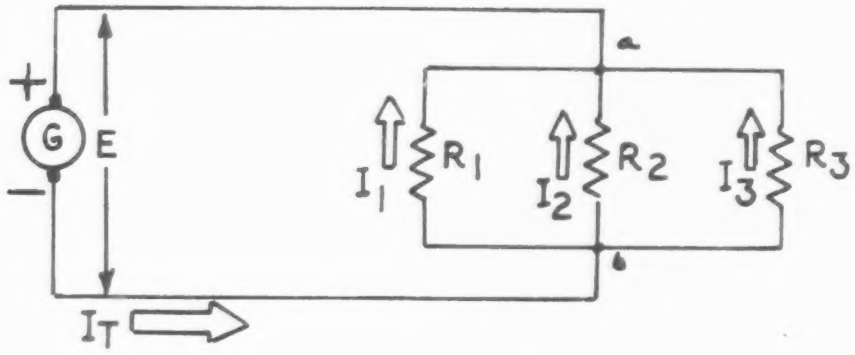
900 watts @ 16Ω

17. Four resistors of 8,000, 1,500, 2,500 and 3,000 ohm are connected in parallel. What is the equivalent resistance of the combination?

655.7 ohms

18. What resistance must be connected in parallel with a 20 ohm resistance to create a 4 ohm equivalent resistance?

5 ohms



19. In the circuit shown above; R_1 = 16 ohms, R_2 = 4 ohms, 1_3 = 4 amp, and E = 32 volts. Find (a) I_t, (b) I_1, (c) I_2, (d) R_3, (e) total power.

(a) 14 amp (b) 2 amp (c) 8 amp (d) 8 ohm (e) 447.99 watts

20. In the circuit shown above, if R_1 and R_2 are both 10,000 ohm resistors, and R_3 is a 5,000 ohm resistor; the total current is 0.40 amp. What value of resistance must be connected between junctions a and b to result in a total current of 0.50 amp?

10,000 ohm

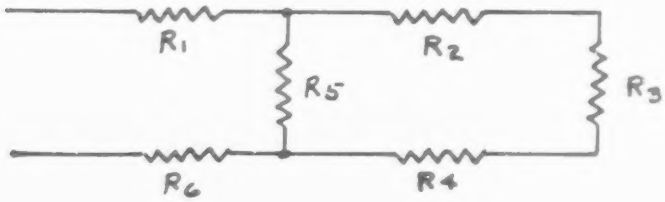
VOLTAGE, CURRENT, AND RESISTANCE IN SERIES-PARALLEL CIRCUITS

Check-up: (1-2-6)

1. Name the steps that you would follow in determining the total resistance of a complex series-parallel circuit.
   - *(a) Re-draw the circuit if necessary to simplify.*
   - *(b) Parallel combinations having branches consisting of two or more resistors in series are added together.*
   - *(c) Use formula for parallel resistance to find total resistance of parallel parts.*
   - *(d) Add the combined parallel resistances which are in series.*

2. Explain why no new formulas are necessary in order to find total resistance in a series-parallel circuit.
   By breaking the complete circuit into parts consisting of simple series and parallel circuits, and then solving each part seperately and combining the parts, no new formula is necessary.

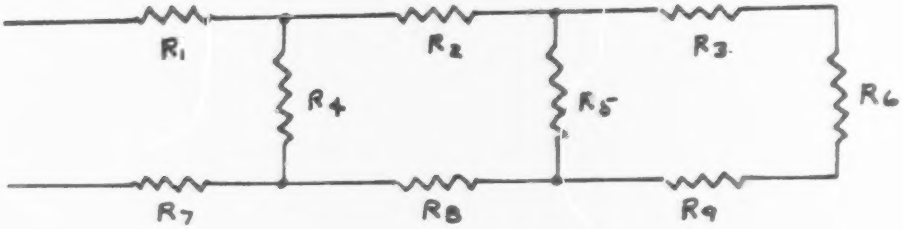
3. Find the total resistance of the following arrangement of resistors, assuming that each resistor has a value of 1 ohm.



R_t = 2.75 Ω

4. Find the total resistance of the following arrangement of resistors, the value of the resistors being:

R_1 = 7 ohms
R_2 = 4 ohms
R_3 = 3 ohms
R_4 = 2 ohms
R_5 = 15 ohms
R_6 = 5 ohms
R_7 = 9 ohms
R_8 = 8 ohms
R_9 = 2 ohms



$R_t = 17.8\ \Omega$

5. Upon what factor does the total current flow in a series-parallel circuit depend?
The total resistance offered by the circuit when connected across a voltage source.

6. What value of current does the sum of all of the branch currents equal in a series parallel circuit?
The total circuit current.

7. What does the total voltage across a series-parallel circuit equal in terms of the voltage drops in the various paths between the two ends of the circuit?
The sum of all the voltage drops in all the various paths will equal the applied voltage.

8. Two resistances; R_1 = 150 ohms, R_2 = 200 ohms, are connected in parallel and this parallel combination is connected in series with a third resistor which equals 620 ohms. If 230 volts is applied to this series parallel

combination: (a) what is the total current of the circuit? (b) how much power is expended in R_2?

(a) 0.326 amp *(b) 3.9 watts*

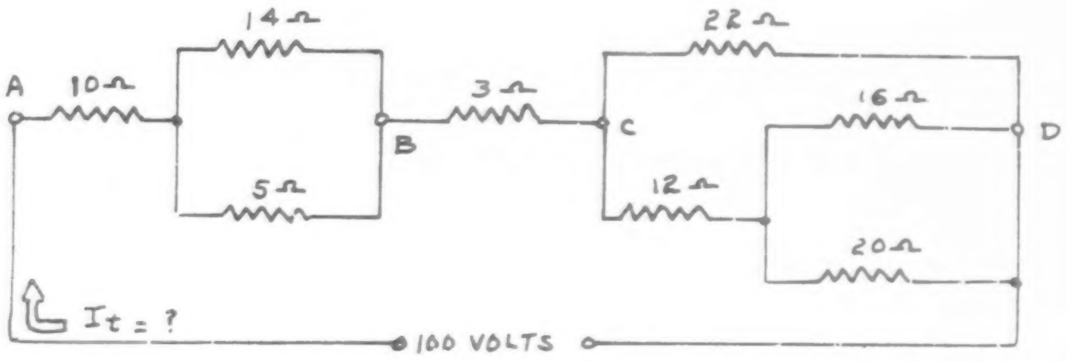
9. In the series-parallel combination in question 8, (a) If R_3 is short circuited, how much power will be expended in R_1? (b) What will be the total current if R_1 is open circuited?

(a) P = 353 watts *(b) 0.280 amps*

10. In a series-parallel circuit a single resistor, R_1, equals 5,600 ohms and is connected in series with a pair of parallel resistors, R_2 and R_3. When a 1,000 volt power supply is connected across this series parallel combination 29.3 ma of current flows through R_2. If R_t equals 7,180 ohms, find: (a) the voltage across R_1, (b) voltage across R_2, (c) the total current, (d) total power expended in the circuit.

(a) 779 volts *(b) 221 volts* *(c) 139 ma* *(d) 139 watts*

11.



Find total current.

3.65 amps

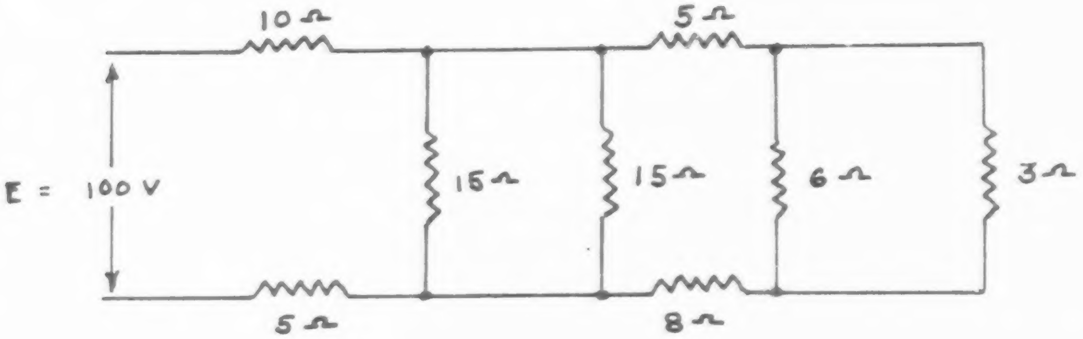
12. Find the total current if C and D were short circuited.

6 amps

13. How much power is expended in the three ohm resistor in problem 11, if A and B are short circuited?

729 watts

14. Reduce the series parallel circuit shown below to an equivalent series resistor.



15. Determine the amount of power that would be expended in the series parallel circuit shown for problem 14.

$$P = \frac{E^2}{R} = \frac{100^2}{20} = 500 \text{ watts}$$

Check-up: (1-2-7)

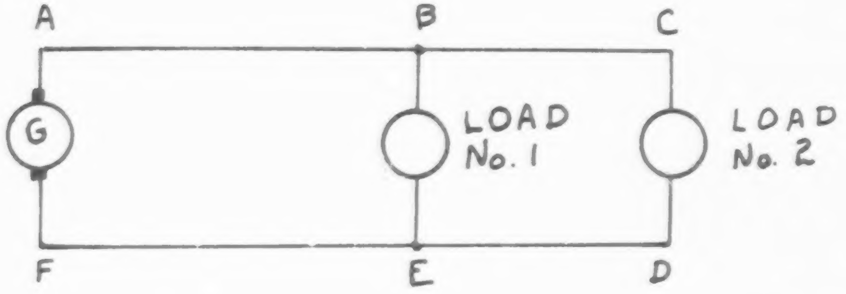
1. What will be the line loss in voltage and in watts per mile in transmitting 10 kilowatts at 240 volts if No. 00 wires are used?

   No. 00 res. = 0.0795 Ω /1000 feet

   = .8395 Ω /2 miles

   1,457 watts

2. In the circuit below, the distance from A to B is 200 feet, and ~~that~~ from B to C is 150 feet. AB and EF are No. 6 wire, and BC and DE are No. 14 wire. Load No. 1 draws 35 amp. and load No. 2 draws 10 amp. The generator develops 230 volts brush potential. (a) What is the voltage at Load No. 1? (b) Power lost in the lines is how much?



   (a) 222.7 volts *(b) 403.8 watts*

3. If in problem 2, the distance from A to B is 100 ft., and ~~that~~ from B to C is 300 ft., AB and EF are No. 10 wire, and BC and DE are No. 14 wire; load No. 1 requires 15 amp and Load No. 2 draws 7.5 amp from the generator which develops 120 volts brush potential. (a) What is the voltage at load No. 1 (b) Voltage at load No. 2? (c) What power is lost in the lines?

   (a) 115.42 volts *(b) 103.8 volts* *(c) 190 watts*

4. A No. 0 two-wire feeder was originally installed to carry a load of 100 amperes, but the load grew to 230 amperes. A repairman attempted to help the situation by paralleling the line with a feeder of No. 1 size. Both feeders were rubber covered wire. Do the two feeders together have sufficient carrying capacity?

   No

5. If we assume the lines to be 500 feet long in question 4 above, how many volts drop could be expected with that increased loading on parallel lines? How much power is expended in the line?

Total Resistance out & back of parallel wires = .0559 amp

$E = IR$ $\qquad$ $P = I^2R$

$E = 230 \text{ amp} \times .0559 \text{ amp}$ $\qquad$ $P = (230)^2 \times .0559$

$E = 12.86 \text{ volts}$ $\qquad$ $P = 2957 \text{ watts}$

(a) 12.86 volts

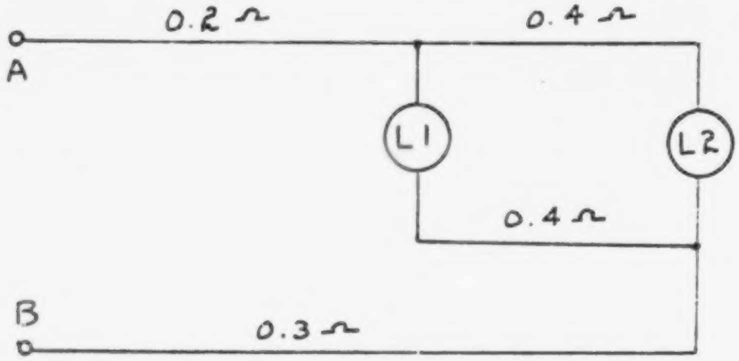
(b) 2.957 kw

6. A generator with a constant potential of 240 volts is to supply power to a 12 kilowatt load one half mile away. If not over 10% voltage drop is allowed in the line, what size wire must be used?

No. 00

7. In the circuit below, L1 equals a load of 4 amp, and L2 represents a load of 2.0 amp. If the source voltage applied to points A and B is 120 volts, find (a) voltage across L1. (b) Voltage across L2.

(a) 115.4 volts *(b) 116.2 volts*



8. A 2 horse power d-c motor is to be installed on 230 KV motor operated disconnect switch. The motor draws 36 amp at 48 volts when connected to its mechanical load. A 48 volt battery, located 100 feet from the motor, will be used to supply power to the motor. If it is desired to limit the voltage drop in the wires to no more than 2 volts--what size wire must be run from the battery to the motor?

No. 4 wire size

9. If a 2 horse power d-c motor rated 125 volts could be used for the 230 KV motor operated disconnect in question 8, and the motor draws 14 amp, what size wire could be used when a 125 volt battery is used to supply the power? Limit the voltage drop to no more than two volts.
No. 10 wire size

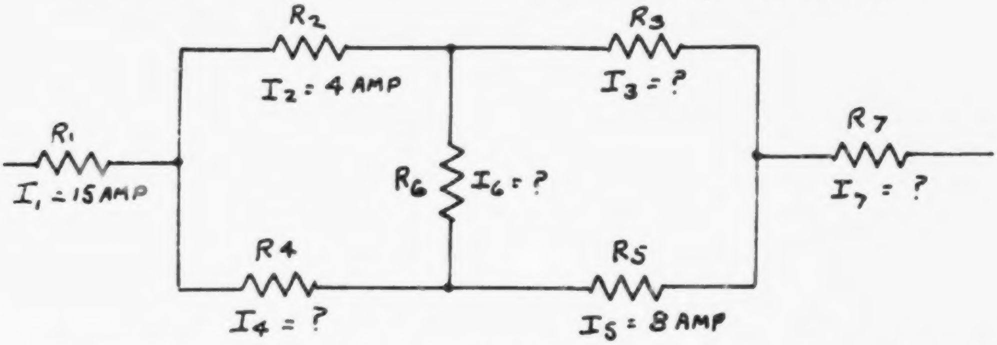
10. Supply the missing words—For transmitting a specified amount of power, the line losses can be reduced by increasing the (a)*wire size*.
(b) Power lost in the lines is due to the *current* drawn by the load.

Lesson 1-2-8

KIRCHHOFF'S LAWS APPLIED TO COMPLEX CIRCUITS

Check-up: (1-2-8)

1. In the sketch below, we are given the values of I_1, I_2, and I_5. Using Kirchhoff's First Law, which states that the algebraic sum of the currents at any junction of conductors is zero, find I_3, I_4, I_6, I_7.



At Junction A: $I_1 - I_2 - I_4 = 0$ *(also)* $I_4 = I_1 - I_2 \therefore I_4 = 15 - 4$

$I_4 = 11$ *amps*

At Junction B: $I_3 - I_2 - I_6 = 0$ $I_3 = I_2 + I_6$ $I_3 = 4 + 3$

$I_3 = 7$ *amps*

At Junction C: $I_4 - I_6 - I_5 = 0$ *(also)* $I_6 = I_4 - I_5 \therefore I_6 = 11 - 8$

$I_6 = 3$ *amps*

At Junction D: $I_7 - I_3 - I_5 = 0$ $I_7 = I_3 + I_5$ $I_7 = 7 + 8$

$I_7 = 15$ *amps*

(Shown is method of solution as per Kirchhoff's 1st Law)

2. Solve both parts of the problem by Kirchhoff's Law:

   a. Kirchoff's Second Law states that the algebraic sum of the electromotive forces and voltage drops around any closed electrical circuit is zero. If three resistors are connected in series across a voltage of 120 volts and the voltage drops of R_2 and R_3 are 10 and 15 volts, respectively, what is the voltage drop across R_1?

95 volts

Method of Solution:

$E_t - E_1 - E_2 = 0$

$E_1 = E_t - E_2 - E_3 \qquad E_1 = 120 - 10 - 15 = 95$ *vol*

b. Assuming that R_1 is equal to 50-2/3 ohms, R_2 equals 5-1/3 ohms and R_3 equals 8 ohms, what is the value of current in the circuit?

1.875 amp

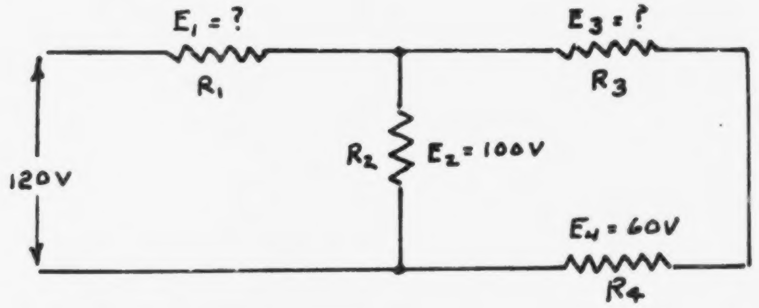
Method of Solution:

$$120 - 50 - \frac{2}{31} - 5 - 131 = 0$$

$$120 - \frac{152I}{3} - \frac{16I}{3} = \frac{24I}{3} = 0$$

$$64I = 120 \qquad \text{or} \qquad I - 1.875$$

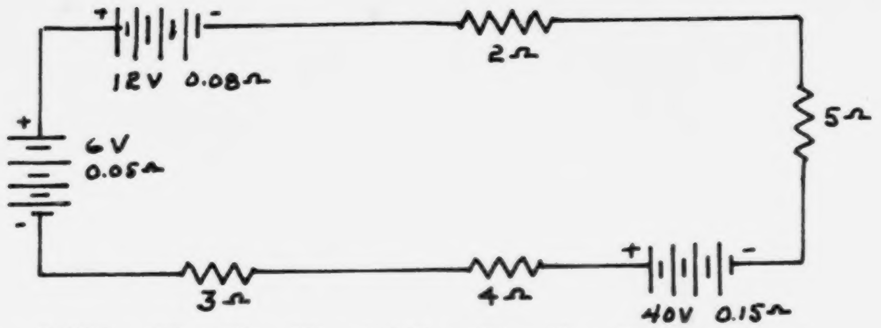
3. Using Kirchhoff's Second Law, find the voltage drops across R_1 and R_3 in the following circuit diagram. The total voltage is 120 volts and the voltage drops across R_2 and R_4 are 100 volts and 60 volts, respectively. (Hint: Reduce this diagram to its simplest form.)



$E_t - E_1 - E_2 = 0 \quad E_1 = E_t - E_2 \qquad E_1 = 120 - 100 = 20$ *volts*

$E_2 = E_3 + E_4 \quad E_3 = E_2 - E_4 \qquad E_3 = 100 - 60 = 40$ *volts*

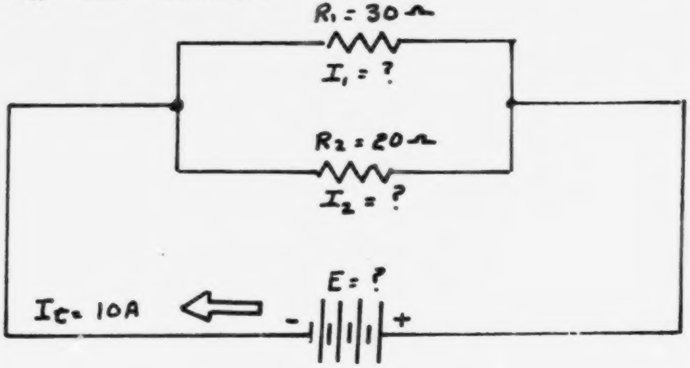
4. Kirchhoff's Second Law states that in a closed electrical circuit the sum of all the voltage drops and the electromotive forces in that circuit equals zero. Applying this law to the following circuit, how much current flows?


12V 0.08Ω
2Ω
5Ω
6V
0.05Ω
3Ω
4Ω
40V 0.15Ω

$6 - 0.05I - 3I - 4I + 40 - 0.15I - 5I - 2I - 12 - 0.08I = 0$

$34 - 14.28I = 0;\ 14.28I = 34;\ I = 2.38$ amp

5. A battery supplies 10 amperes to two resistors of 30 ohms and 20 ohms connected in parallel. If the internal resistance of the battery and the resistance of the connection leads is ignored, what is the battery voltage and how much current flows through each resistor?


R₁ = 30Ω
I₁ = ?
R₂ = 20Ω
I₂ = ?
E = ?
Iₜ = 10A

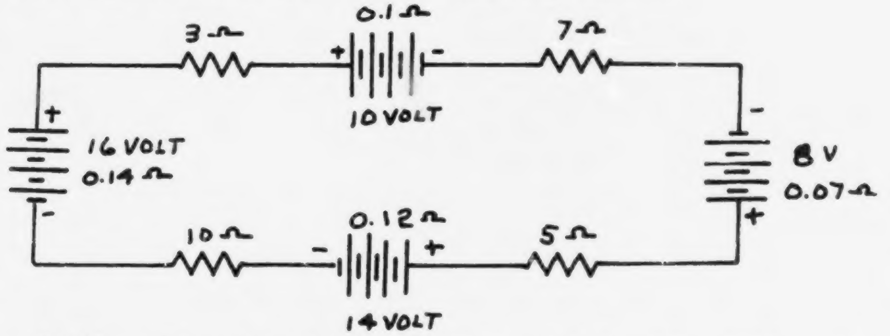
$I_1 = \frac{120}{30} = 4$ Amp

$I_2 - \frac{120}{20} = 6$ Amp

$I_t - I_1 - I_2 = 0$ OR $I_t = I_1 + I_2 : I_1 = \frac{E}{30}$ & $I_2 = \frac{E}{20}$

$10 - \frac{E}{30} - \frac{E}{20} = 0 : \frac{2E + 3E}{60} = 10;\ SE = 600$ then $E + 120$ Volts

6. How much current will flow in the following circuit?


3Ω
0.1Ω
7Ω
10 VOLT
16 VOLT
0.14Ω
8V
0.07Ω
10Ω
0.12Ω
5Ω
14 VOLT

$16 - 0.14I - 10I - 14 - 0.12I - 5I + 8 - 0.07I - 7I - 0.1I - .10 - 3I = 0$

$15 - 14 + 8 - 10 - 25.43I = 0 \quad ; \quad 25.43I = 0 \therefore I = 0$

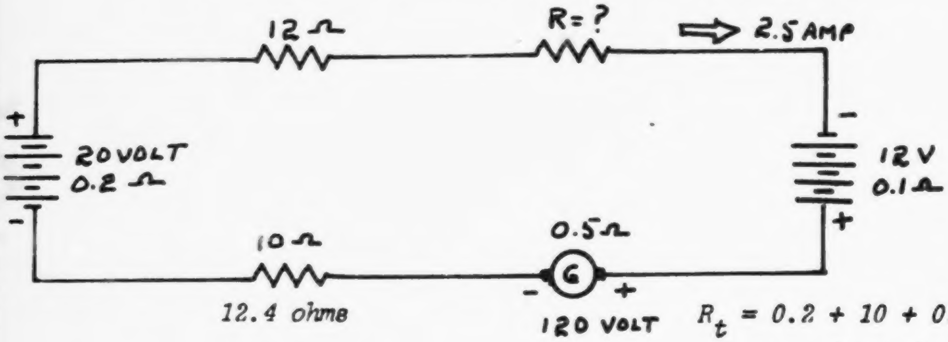
7. Three resistors, R_1 equals 2 ohms, R_2 equals 5 ohms, R_3 equals 3.6 ohms and an unknown resistor, are connected in series across a 24-volt battery whose internal resistance is 0.1 ohm. If a current of 1.2 amperes flows in the circuit, what is the value of the unknown resistor? Prove this according to Kirchhoff's Second Law.

9.3 Ω

8. A 60-volt battery and a generator, with the positive of the generator connected to the positive of the battery, supply 7 amperes to two resistors connected in parallel. The values of the resistors are 15 ohms and 20 ohms. (a) What is the voltage of the generator? (b) What are the voltage drops of the resistors? (c) How much current flows in each resistor?

(a) 120 volts, (b) 60 volts, (c) I_1 *= 3 AMPS* I_2 *= 4 AMPS*

9. What is the value of R in the following circuit diagram?



12.4 ohms

$R_t = 0.2 + 10 + 0.5 + 0.1 + R + 12$

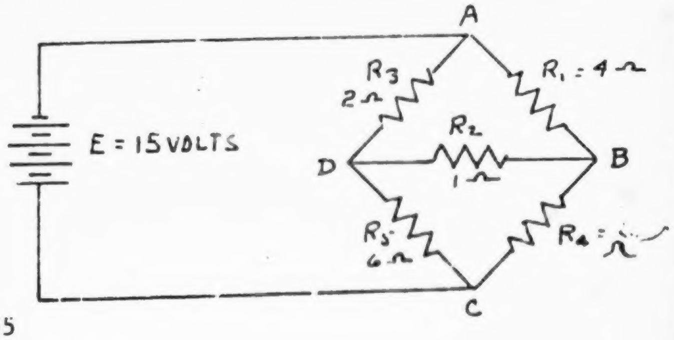
$R + R_t - 22.8$ ohms

$R_t = \frac{E}{I} = \frac{120 - 20 - 12}{2.5} = 35.2$ ohms

$R = 35.2$ ohms $- 22.$ohms

$R + 12.4$ ohms

10. We have a network of resistors as shown below. (a) Find the equivalent resistance between points a and c. (b) How much current flows with 15 volts impressed across a and c?



(a) 4.096 Ω , (b) 3.66 Ω

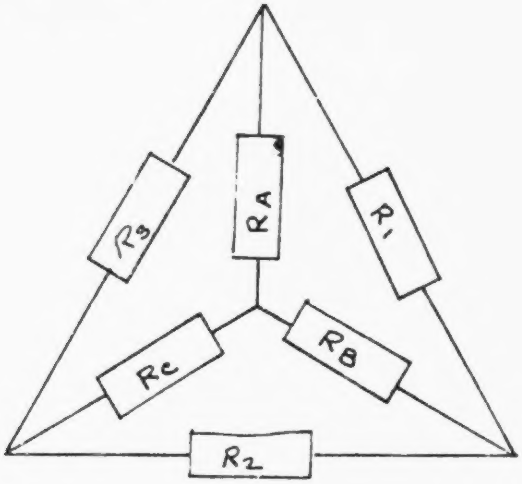
Note: An alternate solution to problem 10 is to use the equations for converting from a delta network to an equivalent wye network.

Equivalent WYE from a Delta Network

$$R_A = \frac{R_1 R_3}{R_1 + R_2 + R_3}$$

$$R_B = \frac{R_1 + R_2}{R_1 + R_2 + R_3}$$

$$R_C = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$



Lesson 1-3-1

REVIEW OF MATHEMATICS

Check-up: (1-3-1)

Solve the following right triangles for the unknown elements:

1. $R = 73.6$, $\theta = 15.0°$

   $Z = 76.2$, $X = 19.7$, $\phi = 75°$

2. $R = 425$, $\theta = 23.6°$

   $Z = 464$, $X = 186$, $\phi = 66.4°$

3. $X = 17.0$, $\theta = 69.1°$

   $Z = 18.2$, $R = 6.5$, $\phi = 20.9°$

4. $X = 38.0$, $\theta = 73.3°$

   $Z = 39.7$, $R = 11.4$, $\phi = 16.7°$

5. $Z = 70.0$, $R = 63.5$

   $\theta = 24.9°$, $\phi = 65.1$, $X = 29.5$

6. $Z = 51.7$, $R = 10.3$

   $\theta = 78.5$, $\phi = 11.5°$, $X = 50.6$

7. $Z = 0.403$, $X = 0.290$

   $\theta = 46.0°$, $\theta = 44.0°$, $R = 0.280$

8. $Z = 48.7$, $X = 48.4$

   $\theta = 83.6$, $\phi = 6.4°$, $R = 5.40$

9. $R = 8.10$, $X = 21.1$

   $\theta = 69°$, $\phi = 21°$, $Z = 22.6$

10. $R = 454$, $X = 1,530$

    $\theta = 73.5°$, $\phi = 16.5°$, $Z = 1,596$

Check-up: (1-3-2)

Find the horizontal and vertical components, denoted by R and X, respectively, of the following vectors. Check the mathematical solution of each by drawing a vector diagram to scale.

1. 42.0 at 81.2°
   R = 6.43, X = 41.5
2. 108 at 10.9°
   R = 106, X = 20.4
3. 1.92 at 40.0°
   R = 1.47, X = 1.23
4. 1,600 at 106.5°
   R = - 454.4, X = 1534
5. 72 at 180°
   R = - 72, X = 0

Find the resultant forces of the following vectors.

6. 527 at 0° and 600 at 90°
   Z = 799 /48.7°
7. 195 at 90° and 95.9 at 0°
   Z = 217.3 / 26.2°
8. 32.3 at 0° and 32.3 at 90°
   Z = 45.7 /45°
9. 5.8 at 90° and 95.9 at 0°
   Z = 96.1 /86.5°
10. 234 at 90° and 730 at 0°
    Z = 766.6 /17.3°
11. Add 5.4 /31.5° and 8.37 /-75.4° and express the sum in polar form.
    8.548/-38.2°
12. Subtract 5.92 /51.3° from 17.1 /-32.2° and express the result in polar form.
    17.45/-51.9°

Subtraction of phasors in rectangular form

Polar Form		*Rectangular Form*
17.1 /-32.2°	=	*14.47 - j 9.11*
5.92 / 51.3°	=	*3.70 + j 4.62*
Subtracting Result	=	*10.77 - j 13.73*

Note: To subtract, change the sign of the subtrahend and add algebraically.

Expressing the result in polar form : 10.77 - j13.73 = 17.45 /-51.9°

Check-up. (1-3-3)

1. Why do we use alternating current instead of direct current for the transmission of electric power?
   A-C is cheaper for power companies to produce and distribute to their customers and also more versatile. A-C is easy to transform from low to high voltage. By raising voltage and lowering current, power losses are kept to a minimum. An exception to this general practice is the D.C. intertie with California which is only economical on very long transmission lines or submarine cables - Vancouver B.C. to Victoria for example.

2. What is the limiting factor in a transmission line? Is it conductor size, voltage, insulation or what is it that limits transmission lines capabilities?
   All these items affect transmission. Larger conductors are not practical and at present time insulation is a problem if the voltage is raised above 1 million volts (1,000 kv). However transmission systems above the 1,100,000 volts are presently being developed.

3. What limits the amount of current that can be carried on a transmission line?
   The size of the conductors--the heating of the conductors.

4. What is a cycle? What is an alternation?
   A cycle covers one complete range of the output voltage or current from a generator. The voltage starts at zero and consists of one posive loop and one negative loop. One half cycle is called an alternation.

5. What is the effective value of alternating current in percentage of the maximum value?
   70.7%

6. Alternating voltage is an electromotive force which changes continuously with time, rising from zero to a maximum value in one direction, decreasing to zero, rising the same maximum value in the opposite direction, again decreasing to zero, and then repeating these values at equal intervals of time.

What is a waveform of a current or a voltage made to represent? What kind of wave form does alternating current or alternating voltage have?

A wave form is a plot on a graph and shows the magnitude and direction of the current or voltage at every instant of time. A-C wave forms are symmetrical about the horizontal axis.

7. **What is frequency?**

   The number of cycles generated in one second.

8. **At 60 hz how much time is consumed by the voltage going from 0 degrees to 270 degrees?**

   $\frac{1}{60} \times \frac{3}{4}$ *cycles* $= \frac{1}{80}$ *sec. or .0125 sec. or12.5 millisecond*

9. **We use 60 hz in this country for our alternating current supply. Why do we not use a lesser frequency--say, 10 or 15 hertz?**

   With this low frequency, there may be a visible flickering of incadescent lamps.

10. **What is the maximum voltage in terms of the effective values of alternating voltage?**

    Maximum or peak voltage is 1.414 times greater than effective value voltage. Effective value is equal to 0.707 times peak value.

11. **How does alternating current differ from a varying direct current?**

    Alternating current flows first in one direction, and then reverses and flows in the other. Direct current, the magnitude may vary, but the direction never changes.

12. **Alternating current traces a curve called a "sine wave." What is a ~~sign~~ wave and why is it so called?**

    A ~~sign~~ wave is graphically produced by a simple A-C generator with symetrical positive and negative portions above and below the zero reference line--it is a plot or graph of all the instantanious values. Any point on the graph is a function of the sine of the angle between the magnetic field and the motion of the armature.

13. **How many hertz equal 1,500 kilohertz? How many kilohertz equal 15,000 hertz?**

    1,500,000 hz   15 khz

14. **Explain the difference between electrical and mechanical degrees.**

Generators are built to operate for a specific speed and at a specific frequency. The speed of rotation is a function of frequency and the number of poles. Electrical degrees are used to measure a cycle--assume 360° for a full cycle. In a two pole generator one degree of mechanical rotation would produce one electrical degree--but in a 4 pole generator--one mechanical degree would produce two electrical degrees and etc. $f = \frac{(\text{Pairs of poles})\ (\text{RPM})}{60}$

15. **What is meant by phase? Phase difference?**

Phase difference is measured in degrees and is the angle of difference between two rotating electric vectors, voltages or currents.

16. **What is the effective value of a voltage whose maximum amplitude is 200 volts?**

E_{eff} *- 141.4 volts*

17. **What is the rms value of a voltage whose peak-to-peak voltage is 200 volts?**

rms = 70.7 volts

18. **What is the average value of the output voltage of a 6 volt battery? What is the rms value?**

E_{av} *= 6 volts* E_{rms} *= 6 volts*

19. **The voltage measured at a household electric outlet is 119 volts. This is the rms value of the voltage. What is the peak voltage? What is the average voltage?**

rms - 119 volts E_{pm} *= 168.266 volts* E_{av} *= 107.18 volts*

20. **One alternation of a sine wave takes 4/1,000 of a second. What is the frequency of the wave?**

125 herts

NOTE: One alternation is 1/2 cycle

Then one cycle = $\frac{8}{1{,}000}$ *of a second*

or .008 sec/

then if

$\frac{.008 \text{ sec}}{1 \text{ sec}} = \frac{1 \text{ cy}}{\text{cy/sec}}$

cyc/sec = 125 hertz

Check-up: (1-3-4)

1. If a 4-pole generator is turned by a water wheel at a speed of 1800 r.p.m., what would be the frequency of the generator?

   $f = \frac{pairs \times rpm}{60} = \frac{2 \times 1800}{60} = - 60\ hz$

2. An alternator with 8-poles has a speed of 900 r.p.m. What frequency would it operate at?

   $f = \frac{pxs}{60} = \frac{4 \times 900}{60} = 60\ hz$

3. If a 12 pole generator operates at a speed of 250 r.p.m., what would be the frequency of the generator?

   $f = \frac{pxs}{60} = \frac{6 \times 250}{60} = 25\ hz$

4. A sine wave voltage produced by an a-c generator has a maximum value of 170 volts. Determine the instantaneous voltage at 45 electrical degrees after crossing the zero axis in a positive direction.

   120.2 volts

5. An alternator produces a maximum voltage of 325 volts. What is the instantaneous value of this voltage at 90 degrees,
   at 140 degrees?

   325 volts @ 90°
   208.9 volts @ 140°

6. Two a-c generators are to be operated in parallel at the same frequency. Generator No. 1 has 14 poles and turns at a speed of 1800 r.p.m. Generator No. 2 has 10 poles.

   (a) What is the frequency of generator No. 1?

   210 hz

   (b) What is the speed of generator No. 2, so it may operate satisfactorily in parallel with generator No. 1?

   2520 rpm

7. **What is the effective value of an alternating voltage whose maximum value is 311 volts?**
   219.88 volts

8. **Using the values obtained in question 7, what would be the instantaneous value for the voltage at 245 degrees?**
   281.8 volts

9. **If an alternating e.m.f. has the instantaneous value of 280 volts at 50 degrees, what is its value at 150 degrees?**
   365.54 volts E maximum
   and 182.8 volts Instantaneous

10. **What is the maximum value of an alternating current, if the instantaneous value at 310 degrees is minus 80 amp?**
    104.4 amps

Lesson 1-3-5

RESISTANCE IN A-C CIRCUITS

Check-up: (1-3-5) Write out the answers to the following review questions found on page 3-41 of Electricity One-Seven.

1. What are eddy currents? How are they related to frequency?

   When an a-c current flows in a conductor it causes voltages to be sent up inside the conductor which in turn cause small independent eddy currents to exist. More pronounced with higher frequency.

2. What is skin effect? Is it present in d-c circuits?

   The concentration of current flow near the surface of a conductor---NO.

3. How is skin effect overcome in power cables? Why does this work?

   Skin effect is reduced by using stranded wire; the total surface area of the wires is greater than that of a single conductor.

4. What is the average power dissipated in an a-c circuit where the maximum voltage is 20 volts, and the maximum current is 40 amperes?

   $P = \frac{E_{pk} \times I_{pk}}{2} = 400$ *watts*

5. What is the average power dissipated in an a-c circuit where the effective voltage is 70 volts and the effective current is 30 ampers?

   $P = E_{eff} \times I_{eff} = 70 \times 30 = 2.1$ *KW*

6. The instantaneous current through a resistor is 14 amperes and the instantaneous voltage across the resistor is 28 volts. What is the instantaneous power developed?

   $P_{inst} = E_{inst} \times I_{nst} = 14 \times 28 = 392$ *watts*

7. The peak value of the voltage in an a-c circuit is 100 volts and the effective current is 7 amperes. What is the average power dissipated?

   $E_{eff} - E_{pk} \times .707 = 100 \times 0.707 = 70.7$ *volts* $\therefore 70.7 \times 7 = 494.9$ *watts*

8. **The peak power developed across a resistor is 1500 watts, when the effective voltage across the resistor is 500 volts. What is the average current over one alternation?**

$E_{pk} = E_{eff} \times 1.414$; $I_{pk} = \frac{P_{pk}}{E_{pk}} = 1.35$ *amp.*

9. **The average value of one alternation of a sine-wave voltage is 75 volts, and the peak value of the current is 3 amperes. What is the average power developed?**

$3 \times .707 = 2.12$ *amp eff.* $75 \times 1.11 = 83.2$ *volts eff.* $p = 2.12 \times 83.2 = 176.2$ *watt*

10. **The average power developed across a resistor is 2000 kilowats, and the peak-to-peak voltage is 200 kilowolts. What is the value of the effective current through the resistor?**

$E_{eff} = 0.707 \times I_{pk}$ $\quad I = \frac{P}{E} = \frac{2000\ kw}{70.7\ kv} = 28.3$ *amp*

$E_{eff} = 0.707 \times 100{,}000$

$E_{eff} \times 70.7\ kv$

Lesson 1-3-6

INDUCTANCE IN A-C CIRCUITS

Check-up: (1-3-6)

1. What properties, in addition to resistance, limit the current in an a-c circuit?
   Inductive reactance and capacitive reactance oppose the flow of a-c current.

2. What rule gives the direction of the magnetic field around a current carrying conductor? State the rule.
   The left hand rule. If your fingers are wrapped around the conductor, with your thumb in the direction of the electron flow, they will indicate the direction of the magnetic field.

3. For a conductor moving through a magnetic field, what rule gives the direction of the induced emf when the direction of the magnetic field is known? State the rule.
   The right hand rule. If the thumb, forefinger, and middle finger of the right hand are held at right angles to one another, with the thumb pointing in the direction in which the conductor is moving and the forefinger pointing in the direction of the magnetic field, then the middle finger points in the direction of the induced emf.

4. What factors determine the magnitude of the induced emf?
   Strength of the magnetic field, length of the conductor, speed of the conductor, and the direction of the magnetic field.

5. What is self-induction?
   When a varying current flows in a conductor, it creates a magnetic field which induces an emf in the conductor -- counter to the applied force -- this is self induction.

6. On what two factors does the magnitude of a self-induced emf depend?
   The frequency of an a-c current and its amplitude determine the magnitude of the self-induced emf.

7. **What is meant by counter emf? By back emf?**
Since the action of the induced emf is to oppose the applied voltage, it is often called the Back emf or counter emf.

8. **State Lenz's Law.**
Lenz's Law states: A change in current produces an emf whose direction is such that it opposes the change in current.

9. **What determines the direction of the self-induced emf? How does Lenz's Law explain this?**
When a current is decreasing, the induced emf is in the same direction as the current and tries to keep the current from decreasing. When the current is increasing, the polarity of the induced emf is opposite to the direction of the current. The induced emf and the applied voltage are always 180 degrees out of phase.

10. **How can self-induction be explained from an energy standpoint?**
Self-induction can be considered an exchange of energy when the magnitude of the current through a conductor changes.

Lesson 1-3-7

INDUCTANCE

Check-up: (1-3-7)

Write out the answers to the following review questions found on page 3-70 of Electricity One-Seven.

1. Define inductive time constant.
   The time required for the current to either increase to 63.2% of its maximum value, or to decrease 63.2% from its maximum value is one time constant. The inductive time constant is equal to t-L/R.

2. How many time constants does it take for the current to reach 63.2 percent of its maximum value in a d-c circuit?
   One

3. In what units are time constants measured?
   seconds, milliseconds(1/1000 sec) or microseconds (1/1,000,000)

4. What is the total inductive reactance of three coils in series whose reactances are 5, 5, and 10 ohms?
   5 + 5 + 10 = 20 ohms

5. What would be the total inductive reactance for the coils in Question 4 if they were in parallel?
   2ohms

6. What is the inductive reactance of a 10-millihenry coil at frequencies of 100 htz., 1000 htz., 10 kilo hertz, 100 kilo hertz, and 1 mega hertz?

   $X_L = 6.28\Omega$ @ 100 hz $X_L = 62.8\Omega$ @ 1000 hz $X_L = 6,280\Omega$ @ 100 khz and $62,800\Omega$ @ one M-hz.

7. **What is the phase relationship between current through, and the voltage across, an inductor? Why is this so?**

   The applied voltage leads the current by 90°. A changing magnetic field induces a voltage in an inductor that opposes the change in current producing it. A-C is constantly changing and causes the current to lag.

8. **What is the value of the time constant for a circuit consisting of a 5000-ohm resistor and a coil having an inductive reactance of 1.884 ohm at 60 htz.?**

   $t = 1 \text{ microsecond or } \frac{1}{1{,}000{,}000} \text{ or } t = \frac{.0049976}{5{,}000} = .000{,}000{,}9 \text{ sec.}$

9. **It takes 10 seconds for the current to drop to zero after the switch is opened in a d-c circuit consisting of a battery, switch, resistor, and coil. What is the circuit time constant?**

   $t = \frac{10 \text{ sec}}{5} = 2 \text{ seconds}$

10. **If the value of the resistor of question 9 is 100 ohms, how many 40-henry inductors are needed to provide the inductance? Are they connected in series or in parallel?**

    5 in series

Lesson 1-3-8

MUTUAL INDUCTANCE

Check-up: (1-3-8)

1. What causes the emf of self-induction?
   The expansion and contraction of the magnetic field as the current varies. An emf is induced in any wire that moves in a magnetic field. In this case it is the field that moves.

2. What is the effect of this emf of self-induction called?
   inductive reactance or counter E.M.F.

3. What does inductance do to current that is increasing in a coil? To a current that is decreasing in a coil?
   Opposes any change in circuit current.

4. How may we increase the induced emf?
   Increase current, frequency, length of conductor.

5. Is there any difference between the emf of mutual induction and the emf of self-induction?
   Mutual induction is a seperate conductor.

6. A magnetic field or flux (circular lines of force) enshrouds every conductor through which electricity flows. Can mutual induction exist between two coils when there is no change in the current, that is to say the current is direct current?
   NO

7. What occurs when the flux of one coil, called the primary coil, cuts the turns of the secondary coil? Explain how a current or emf can be generated in a circuit that is not even in electrical contact with the first circuit. Name one device which makes use of this principle.
   Energy is transferred from one circuit to another without a physical connection between the two by mutual induction. The transfer is accomplished by means of the magnetic field--a transformer.

8. Explain how energy may be transferred from one circuit to another using a battery, switch, meter, and two inductors.
By mutual inductance--when the switch is closed or opened--a change in current flow causes magnetic fields to cut conductors.

9. What is the phase relationship between the currents that flow in two circuits that are mutually inductive?
The secondary is 180° out of phase with the primary.

10. What is the co-efficient of coupling between inductances?
The degree of flux linkage is expressed by a factor called the coefficient of coupling. When all the flux lines from one coil cut or link the other coil, the coefficient of coupling is one.

Lesson 2-4-1

CAPACITANCE

Check-up: (2-4-1)

1. You will remember that inductance opposes any change in the circuit current. What is the opposition to any change in the circuit voltage called?
   Capacitive reactance.

2. When does capacitance affect direct-current voltage?
   In fluctuating d-c circuits

3. What is the letter used to denote capacitance? What quantity of capacitance does this letter represent?
   The letter C - farads

4. Upon what does capacitance depend?
   Three factors--surface area of the plates, the distance between the plates and the insulating material between the plates (dielectric).

5. If we apply direct current to a capacitor, how long does current flow?
   A capacitor blocks d-c. Therefore, once the capacitor is fully charged, no further current will flow in the circuit.

6. If alternating-current voltage is applied to a capacitor, how long does the current flow?
   A-C current will flow through the capacitor continuously.

7. Does alternating current actually pass through the insulating material between the capacitor plates?
   No, only a very small amount of leakage current which can be considered as negligible. If current passes through the dielective, the capacitor is defective.

8. **What precaution should be taken when discharging a capacitor regardless of whether the voltage used to charge it is direct current or alternating current?**
One should not make any body contact until the capacitor is discharged.

9. **Using direct current, a capacitor is repeatedly charged and discharged. Each time ~~that~~ it is discharged you note that the resulting arc or spark is the same size. If this charging and discharging of the capacitor with alternating current is repeated, the spark occurring at discharge varies in size and intensity. Explain why this is true.**
A capacitor charges until the voltage built across it equals the source voltage which with a d-c source is always the same--in an a-c circut the voltage is continual changing.

10. **How can you prove that capacitors block direct current? That capacitors appear to pass alternating current continuously?**
With an ammeter or a light bulb of the proper size in series with the capacitor and first applying a d-c voltage and then a a-c voltage source.

11. **What is a capacitor discharge?**
A capacitor is said to be discharged when the charges on the plates are neutralized.

12. **Given a circuit consisting of a 100-millampere alternating current milliammeter and a 1-microforad capacitor in series, when 120 volts alternating current is applied, approximately 45 milliamperes will flow continuously. Explain this current flow in the face of the fact that the capacitor plates are separate with an insulating material.**
A capacitor in an a-c circuit is first charged by the voltage being applied in one direction and then the other charging and discharging every cycle-an a-c current therefore continues to flow continuously.

Check-up: (2-4-2)

1. **Describe the construction of a capacitor. What is the material which separates the plates called?**

   The basic capacitor consists of two conductors or plates separated by an insulating material called the dielectric.

2. **Name the factors which affect the capacitance of a condenser.**

   The surface area of the plates--the distance between the plates--the insulating material.

3. **What is the dielectric constant of a capacitor?**

   Indicator of how effective a material is as a dielectric--air is assigned the value of one.

4. **Give the formula for two capacitors connected in series. What is the formula for two capacitors connected in parallel? In what way does this differ from connecting resistances in series or parallel?**

   Series $C_t = \frac{C_1 C_2}{C_1 + C_2}$ *(Combine the resistances in parallel)*

   Parallel $C_t = c_1 + C_2$ *(Combine like resistances in series)*

5. **Describe a variable air capacitor.**

   Consists of two sets of interleaving metal plates--one set is fixed; the other is mounted on a shaft, and when rotated, moves the plates in between the fixed plates.

6. **What precaution must be observed when using an electrolytic capacitor made to be used on direct current?**

   Care must be taken to connect the capacitor terminals to the correct polarity--the capacitor is polarized.

7. What will be the time constant in seconds of a 1-microfarad capacitor connected in series with a 2-megohm resistor?

   $t = RC = 2 \times 10^{6} \times 1 \times 10^{-6} = 2$ *seconds*

8. What does the time constant equal?

   The time required for the capacitor to charge to 63.2% of its fully charged voltage.

9. What three methods are used to identify capacitors?

   (1.) Printed information, (2.) five dot or six dot, and (3.) color bands using a color code.

10. How does voltage rating affect the size of a capacitor?

    The higher the voltage rating, the more dielectric and spacing between the plates--therefore, the high voltage capacitors are physically larger.

11. There are four capacitors, 2 mfd, 1 mfd, 0.5 mfd, and 0.25 mfd, connected in parallel. What is the total capacitance of this arrangement?

    3.75 mfd.

12. What is the total capacitance of four capacitors connected in series if the capacitance of the four capacitors is 6 mfd, 3 mfd, 4 mfd, and 1 mfd?

    0.5714 mfd

Check-up: (2-4-3)

Write out the answers to the following review questions found on page 3-133 of Electricity One-Seven.

1. **How does a capacitor block d-c?**

   Once the initial charging current has charged the capacitor, the flow of current is blocked by the dielectric.

2. **What are the voltage and current relationships between the capacitor and applied voltages? Between the capacitor current and applied voltage?**

   Current thru a capacitor leads the voltage applied to the capacitor. The applied voltage and counter voltage are 180° apart.

3. **What happens to the capacitor current if the frequency of the applied voltage is decreased?**

   Current thru a capacitor is directly proportional to the frequency. Increase in frequency-increase in current. A decrease in frequency will result in a decrease in current.

4. **What is the opposition to the flow of a-c current offered by a capacitor called?**

   What are its units?

   Capacitive reactance--expressed in ohms.

5. **What is the equation for finding X_c?**

   $$X_c = \frac{1}{2\pi fc} \quad \text{(c in farads)}$$

6. **What is meant by leakage current in a capacitor? What causes it?**

   The dielectric always has some high value of resistance which allows a small amount of current to flow.

7. What is the total capacitance of three capacitors in series, whose values are 10, 10, and 5 microfarads?

$$C_t = \frac{C_1\ C_2}{C_1+C_2} = 2.5 \text{ mfd}$$

8. What is X_c for each capacitor in Question 7, and the total capacitive reactance of 100 hertz? 10 kilo-hertz?

100 h_z *= 636*

10000 h_z *= 6.36*

9. What is the total capacitance of three capacitors in parallel, whose values are 10, 10, and 5 microfarads?

25 mfd.

10. What is the total capacitive reactance for the three capacitors in question 9 at 100 hz? 10 Kilo-hz? 1 Mega-hz?

	100 hz	*10 khz*	*1 mhz*
10 mfd	*159 OHM*	*1.59*	*0.0159*
5 mfd	*318 ohm*	*3.18*	*0.0318*
25 mfd	*63.6 OHM*	*0.636*	*0.00636*

Check-up: (2-4-4)

Write out the answers to the following review questions found on page 3-142 of Electricity One-Seven.

1. What is meant by the power factor of a circuit?

   pf is the ratio $\frac{\text{true power}}{\text{apparent power}}$

   Also equal to the cos of the phase angle between current and voltage.

2. The apparent power in a circuit is 50 volt-amperes and the true power is 40 watts. What is the power factor?

   $\frac{40 \text{ watts}}{50 \text{ volt-amp}} = .80$ *or 80%*

3. Why are paper, mica, and ceramic capacitors so called? Are these fixed or variable capacitors?

   Fixed capacitors get their name from the dielectric material. They are all fixed capacitors.

4. What is meant by the abbreviation WVDC that is found on a capacitor?

   Working voltage d-c . . . The max voltage that can be safely applied to the capacitor.

5. What is an electrolytic capacitor? Can it ever be used in an a-c circuit?

   Essentially it is a polarized capacitor and should not be used on a-c unless especially built for such use.

6. How are capacitors identified?

   Capacitors are marked in some way with their capacitance value; when practical it is printed on the capacitor. A system of color codes or dots is sometimes used.

7. What is meant by rotor and stator plates? Do fixed capacitors have these?

   The plates on a variable capacitor - No.

8. **Why are the polarities of electrolytic capacitors important? Can these always be used for d-c? For a-c?**
With the wrong polarity the electrolytic capacitor conducts like a low-value resistor and may be destroyed by high current. No-not unless specifically designed for a-c.

9. **The power factor of a circuit is 0.5. What is the phase angle between the voltage and current?**
60°

10. **What is the power factor in a pure capacitive circuit? Resistive circuit?**
p.f. of capacitive circuit = 0
p.f. of resistive circuit = 1

Lesson 2-4-5

THE SERIES RL CIRCUIT

Check-up: (2-4-5)

Write out the answers to the following review questions found on page 4-41 of Electricity One-Seven.

1. In a vector diagram of the voltages in a series RL circuit, what circuit quantity is used as the reference vector? Why?

   Current. Current is the same in all parts of a series circuit.

2. What is the 10-to-1 rule for R and X_L in a series RL circuit?

   If X_L or R is 10 times greater than the other, the phase angle of z can be considered as zero or 90° depending on which is larger.

3. What is the resistance of a coil having a Q of 65, when the inductive reactance is 325 ohms?

   $R = \frac{X_L}{Q} = \frac{325}{65} = 5$ *ohm*

4. What is the resistance in a series RL circuit when the impedance is 130 ohms and the inductive reactance is 50 ohms?

   $R = \sqrt{Z^2 - X_L^2}$ $R = 120$ *ohm*

5. What is the phase angle for the circuit in Question 4?

   $\sin \theta = 50/130 = 0.385$

   $\theta = 22.6°$

6. If an applied voltage of 100 volts causes 5 amperes of current in a series RL circuit, what is the circuit impedance?

   $Z = \frac{E}{I} = \frac{100}{5} = 20$ *ohm*

7. The power dissipated in a circuit is 500 watts, the impedance is 10 ohms, and the phase angle is 60 degrees. What is the value of the current in the circuit?
10 amps

8. What is the apparent power of a circuit which dissipates 500 watts, and has a power factor of 0.25?
2000 volt-amp

9. Between what values (the maximum and minimum) can the power factor be found? Why?
Between 0 and 1. The angle between the current and voltage can be as little as 0° or as great as 90°. $Pf = \cos \underline{/\theta}$

10. What is the voltage across the coil in a series RL circuit when the applied voltage is 100 volts, and the voltage across the resistor is 80 volts?
60 volts

Lesson 2-4-6

THE SERIES RC CIRCUIT

Check-up: (2-4-6)

1. How do you show vectors representing resistance, capacitive reactance and impedance?

Resistance

capacitive reactance *Impedance*

2. An inductive reactance and a capacitive reactance can have the same ohmic value, yet there is a difference between them. Explain, and construct vectors showing these differences between them.

(a) $400 \angle 90^\circ$ *ohms*

(b) $400 \angle -90^\circ$ *ohms*

The difference between them is 180°.

3. A series circuit consists of a resistance of 150 ohms and a condenser of 10 mfd. If a potential difference of 120 volts 60 hertz is applied across the circuit, find (a) the impendance of the circuit, (b) the current flowing through the circuit, (c) the potential difference across the resistance, (d) the potential difference across the capacitor.

(a) 304.8 ohms

(b) 394 Ma

(c) 59.1 volts

(d) 104.5 volts

4. What is the resistance in a series RC circuit when the impedance is 130 ohms and the capacitive reactance is 50 ohms?

R = 120 ohms

5. What is the phase angle for the circuit of question 4?

$Z = 130 \angle -22.6^\circ$ *ohm*

6. The applied voltage across a series RC is 100 volts, and causes a current of 5 amperes to flow. What is the magnitude of the impedance of the circuit?

Z = 20 ohms

7. The power dissipated in a circuit is 500 watts, the impedance is 10 ohms, and the phase angle is 60 degrees. What is the value of the current in the circuit?
I = 10 amps

8. Two 10 mfd capacitors are connected in series and this series combination of capacitors is connected in series with a 25 ohm non-inductive resistor. If 240 volts were to be applied to this circuit, how many amperes would flow in the circuit when the frequency is 50 hertz?
Then I = 0.45 amp

9. A noninductive load with a resistance of 30 ohms is connected in series with a capacitor which has a capacitive reactance of 24 ohms. Determine: (a) impedance of the circuit (b) the current in ampers (c) the volts across the resistor when the applied voltage is 240 volts.
(a) Z = 38.4 ohms (b) I = 6.25 amp (c) E = 187.5 volts

10. In question 9 determine (a) the power expended in the circuit (b) the volt-amperes reactive component in VARS for the series circuit (c) the power in volt-amperes.
(a) 1172 watts (b) 50 var (c) 1500 volt-amp

Lesson 2-4-7

SERIES LC CIRCUITS

Check-up: (2-4-7)

1. How do you show vectors representing current, capacitive reactance and inductive reactance in a series circuit?

   Current is always drawn as the reference, inductive reactance is + 90° to current, capacitive reactance is minus 90° to current.

2. An inductive reactance of 600 ohms and a capacitive reactance of 200 ohms are combined in a circuit. (a) What is the impedance of the circuit? (b) If these values are reversed, that is, the inductive reactance equals 200 ohms and the capacitive reactance equals 600 ohms, then what is the impedance of the circuit?

   (a) $Z = X_L = 400 \quad \angle 90^\circ$

   (b) $Z = X_C = 400 \quad \angle -90^\circ$

3. Three henries pure inductive reactance and 0.4 mfd pure capacitive reactance are connected in series, frequency at 60 hertz. (a) What is the impedance? (b) What is the phase angle? (c) What is the power factor? (d) Is the current leading or lagging the voltage?

   (a) $Z = 468$ *ohm* *(b)* $Z = 90^\circ$ *(c) 0* *(d) Lagging*

4. Consider a series LC circuit with an applied voltage of 100 volts, a capacitor with a voltage of 140 volts across it, and an inductor with an inductive reactance of 20 ohms. (a) What current would flow in the circuit? (b) What is the impedance of the circuit? (c) What is the apparent power of the circuit?

   Note: There can be two correct sets of answers:

   (a) 2 amps *(b)* $50 \angle -90^\circ$ *ohms* *(c) 200 volt-amps*

   (a) 12 amps *(b)* $8.33 \angle 90^\circ$ *ohms* *(c) 1200 volt-amps*

5. In question 4: (a) What is the true power of the circuit? (b) What is the phase angle of the current in the circuit: is it leading or lagging?

   (a) 0 for both sets of conditions

   (b) 90° Leading for 1st set or 90° Lagging for 2nd set.

6. In question 4, if the frequency of the applied voltage is doubled, what current would flow in the circuit? (Hint: The voltage across the capacitor would no longer be 140 volts.)

   As in question 4 there can be two answers:

   (1) $I = 20$ *amps*

   (2) $I = 2.93$ *amps*

7. In question 6, what would be the impedance of the circuit? (b) What current would flow in the circuit?

   (1) $Z = 5 \angle 90^\circ$ *(b)* $I = 20$ *amps*

   (2) $Z = 34.167 \angle 90^\circ$

8. In question 4, if the frequency of the applied voltage were halved: (a) What would be the impedance of the circuit? (b) How much current would flow in the circuit? (c) What is the phase angle of the current in the circuit; is it leading or lagging?

   (a) $Z = 130 \angle -90^\circ$ *ohm* *(b)* $I = 0.769$ *amp* *(c) Current leading by 90°*

9. In question 8: (a) What is the apparent power in the circuit? (b) What is the capacitive reactance?

   (a) 76.9 volt-amp

   (b) $X_c = 140$ *ohm*

10. In question 8: (a) What is the inductive reactance? (b) What is the reactive VARS of the circuit?

    (a) $X_L = 10$ *ohm*

    (b) VARS = 76.9

Lesson 2-4-8

SERIES LCR CIRCUITS

Check-up: (2-4-8)

1. The starting winding of a capacitor-start, induction-run motor consists of a resistance of 15 ohms and an inductive reactance of 20 ohms which are in series with a capacitor of 60 mfd. The motor is connected to a 120 volt, 60 hertz power source. (a) What is the impedance of the series circuit? (b) How much current will flow in the circuit?

   (a) Z = 28.5 ohm (b) I = 4.2 amp

2. In question 1: (a) What is the power factor of the circuit? (b) How many watts of power will the start winding require?

   (a) 52.7% P.F.

   (b) 291 watts

3. A relay coil has a resistance of 100 ohms, an inductance of 0.2 henry and is to be connected in series with a 20 mfd capacitor across a 120-volt, 60 hertz power source. (a) What is the total impedance of the circuit? (b) How many amperes will flow in this series circuit? (c) What is the impedance of the relay coil? (d) What is the power factor for this series circuit? Does the current lead or lag the voltage?

   (a) Z = 115.27 ohm (b) I = 1.04 amp (c) Z = 125.2 ohm

   (d) P.f. = 88.21 current leads voltage

4. A series LCR circuit has an applied voltage of 200 volts, an impedance of 100 ohms, an inductive reactance of 50 ohms and a capacitive reactance of 130 ohms. (a) What is the value of the resistance? (b) What is the current in the circuit? (c) What is the phase angle of the circuit? Does the current lead or lag the applied voltage? (d) What is the true power? (e) What is the apparent power?

   (a) R = 60 ohm (b) I = 2 amp (c) 53.2° current leads

   (d) P = 239.6 watts (e) 400 volt-amp

5. A series LCR circuit consists of 8 ohms resistance, 18 ohms inductive reactance and 12 ohms capacitive reactance. (a) What is the impedance of the circuit? (b) What is the true power? (c) What is the reactive power with an applied voltage of 240 volts?

   (a) 10 ohms (b) P = 4608 watts (c) 3457 vars.

6. A coil containing 100 ohms resistance and 0.50 henry inductance is placed in series with 40 ohms of capacitive reactance and a 30 ohm resistance across a 60 hertz 480 volt a-c circuit. How much current will flow in the circuit?

   2.43 amp

7. What is the voltage across the coil in question 6?

   324.33 volts

8. How many watts of power are being expended in the coil in question 6?

   590.5 watts

9. How much power is being expended in the resistor in question 6?

   177 watts

10. (a) Can the voltage across the inductor or the capacitor in series LCR circuit ever be greater than the applied voltage? (b) Can the voltage across the resistor ever be greater than the applied voltage?

    (a) Yes (b) No

Lesson 2-4-9

SERIES RESONANCE

Check-up: (2-4-9)

1. What does the impedance of a series circuit equal when the inductive reactance equals the capacitive reactance? What is this condition called?
   Very low impedance. It equals the DC resistance of the circuit.
   It is called series resonance.

2. A series circuit has a resistance of 60 ohms, an inductance of 63.66 mili-henry and a capacitance of 110 mfd. Determine the frequency at which this circuit will resonate.

   $f = \frac{1}{2\pi\sqrt{LC}}$ $f = 60$ *hertz*

3. What is the value in ohms of the impedance of the circuit in question 2 at resonance?
   $Z = R = 60$ *ohms*

4. If 120 volt, 60 hertz were applied to the series circuit in question 2, what voltage would exist across the inductor?
   48 volts

5. In question 4, what current would flow at resonant frequency?
   2 amps

6. What is the power factor of a series circuit when resonance is reached?
   100%

7. How much capacity is required to obtain resonance at 1,000 kilo-hertz with an inductance of 50 microhenries?
   6.324 forads

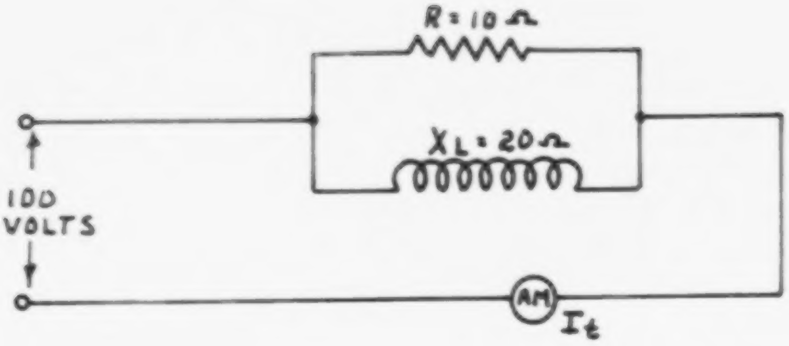
8. What is the value of the current in a series circuit at resonance. Is it minumum or is it maximum?
   Maximum

9. At resonance, is series LCR circuit inductive?
No

10. Most radio receivers employ one or more tuned circuits. Tuning is selecting a signal at one frequency and rejecting signals at all other frequencies. What is another use of series resonant circuits?
Increase load carrying capability of long transmission lines on EHV circuits.

Check-up: (2-4-10)

1.



In the above circuit:

(a) What does I_t equal? *11.2 $\angle -26.6^\circ$ amp*

(b) What does I_R equal? *10 $\angle 0^\circ$ ohms*

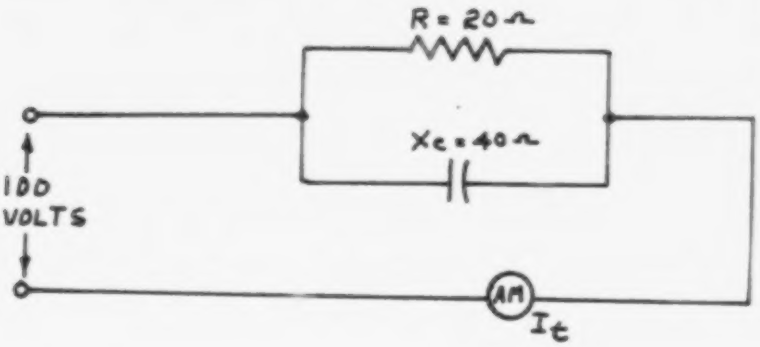
(c) What does I_L equal? *5 $\angle -90^\circ$ amps*

(d) What is the impedance of the circuit? *$Z = 8.95 \angle 26.6^\circ$ ohms*

(e) What is the power? *1,000 watts*

(f) What is the power factor of the circuit? *89.4% Lagging*

2.



In the above circuit:

(a) What does I_t equal? *5.58 amp*

(b) What does I_C equal? *2.5 amps*

(c) What is the impedance of the circuit? *17.9 ∠-26.6° ohm*

(d) What is the apparent power? The true power of the circuit?

558 volt-amp *500 watts*

(e) What is the power factor of the circuit? *89.4% Leading*

3. What determines the flow of current through each individual branch of an alternating-current parallel circuit?

The current through each branch = $I = \frac{E}{Z}$ *when Z = the impedance of that branch.*

4. Why cannot the branch currents be added directly to obtain the total current in an a-c parallel circuit?

The currents may not be in phase with each other.

5. Is direct addition permissible with the various branch currents in a direct-current parallel circuit?

Yes

6. **In a parallel a-c circuit consisting of several branches, what may be said of individual branch-circuit voltages?**
Voltages are the same, equal and in phase across each parallel branch.

7. **What is meant by "equivalent series circuit"?**
An impedance that can be substituted into the circuit and be the same as the parallel combination.

8. **If a 20-ohm resistor and a 15-ohm capacitive reactance are connected in parallel, what would the equivalent series circuit equal?**
7.2 ohm resistor in series with 9.6 ohms of capacitive reactance.
$Z = 12 \angle -53.1^\circ$ *ohm*

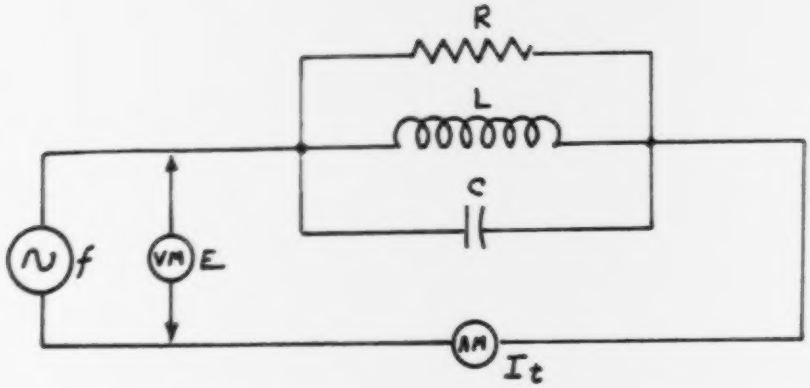
9. **How may the power factor of a parallel a-c circuit be determined?**

$$P.f. = \frac{\text{Watts}}{\text{Volt-Amps}} = \frac{\text{True Power}}{\text{Apparent Power}} = \frac{Z}{R} \text{ for parallel circuits only}$$

10. **In vector diagrams for series RL circuits, what circuit quantity is used as the reference vector? Why? What is the reference vector for parallel RL circuits? Why?**
Series Circuits - Current is used as reference because current is the same in all parts of the circuit.
Parallel Circuits - Voltage is used as reference because voltage is the same across all branches of a parallel circuit.

Check-up: (2-4-11)

1.


R
L
C
f
VM
E
AM
I_t

In the above circuit, if R = 60 ohms, L = 0.064 henry, C = 112.5 microfarads, E = 120 volts, and the frequency = 60 cps:

(a) What does I_R equal? *2 amps*

(b) What does I_L equal? *4.975 amps*

(c) What does I_C equal? *5.09 amps*

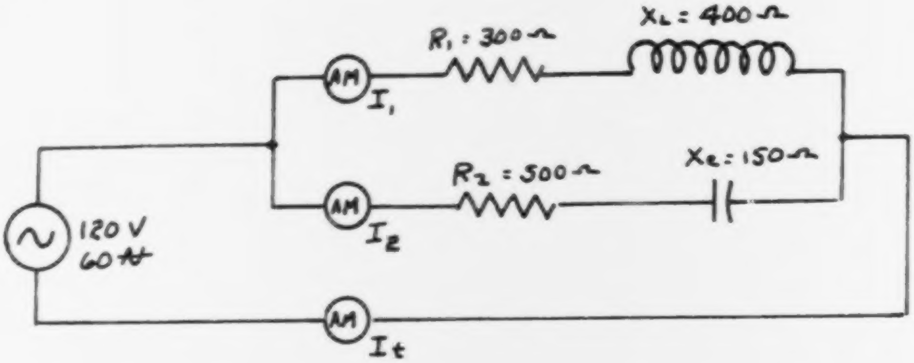
(d) What does I_t equal? *2 amps*

(e) What does Z equal? $60 \angle -3.7^\circ$ *ohms*

(f) What does pf equal? *99.79%*

(g) What amount of power is expended in the circuit? *239.49 watts*

2.


$R_1 = 300\ \Omega$
$X_L = 400\ \Omega$
AM
I_1
$R_2 = 500\ \Omega$
$X_C = 150\ \Omega$
AM
I_2
120 V
60 ~
AM
I_t

(a) What value of current is I_t ? *0.444 amp*

(b) What value of current is I_1 ? *0.24 amp*

(c) What value of current is I_2 ? *0.23* $\angle 16.7^\circ$ *amp*

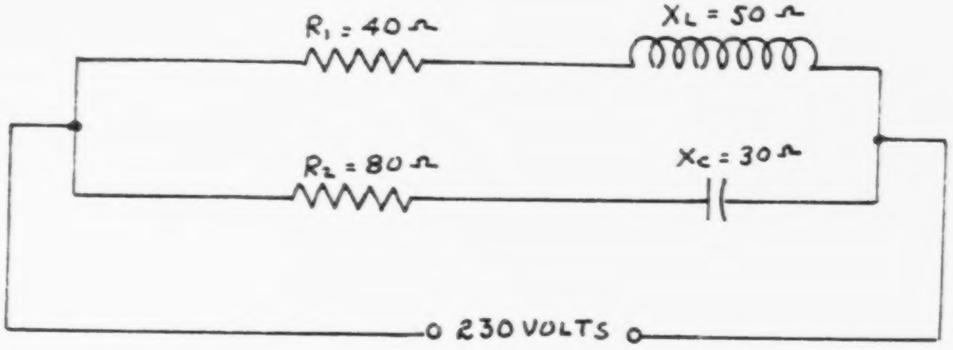
(d) What is the impedance of each branch? *#1 = 300 + j400 = 500* $\angle 53.1^\circ$ *ohm*

#2 = 500 - j150 = 520 $\angle -16.7^\circ$ *ohm*

(e) What amount of power is expended in the circuit? *43.6 watts*

(f) What is the power factor? *94.49%*

3. If 230 volts are impressed across the circuit below:



(a) What is the impedance of branch 1? *Z = 40 + j50 = 64* $\angle 51.3^\circ$ *ohm*

(b) What is the impedance of branch 2? *Z = 80 - j30 = 85.3* $\angle -20.6^\circ$ *ohm*

(c) What is the phase angle of branch 1? *Current lags by 51.3°*

(d) What is the phase angle of branch 2? *Current leads by 20.6°*

(e) How much current will flow in branch 1? *3.6 amps*

(f) How much current will flow in branch 2? *2.7 amps*

(g) What is the value of the total current? *5.12 amps*

(h) What is the total impedance of the circuit? *44.8* $\angle 21.4^\circ$ *ohm*

(i) What is the power factor of the circuit? *93.17%*

(j) What amount of power is expended in the circuit when it is operating at 230 volts? *1095 watts*

Lesson 2-4-12

RESONANCE IN A-C CIRCUITS

Check-up: (2-4-12)

1. What happens to the external-circuit current when the resistance is zero and the inductive reactance and the capacitive reactance are equal, if connected in parallel?
   Theoretically, a parallel resonant circuit has infinite impedance and zero line current.

2. Assuming that we have only inductance, L, and capacitance, C, in an alternating-current series circuit, what is the impedance at resonant frequency? What is the impedance for a resonant parallel circuit?
   Series is very low, parallel resonant impedance is very high.

3. What is meant by "internal circuit"; "external circuit"?
   Internal circuit is the tank circuit of a parallel resonant circuit. The external circuit is that part of the circuit that is external to the parallel L and C Branch.

4. What is meant by "circulating current"?
   The current that circulates inside the tank circuit.

5. Why is parallel resonance sometimes called "anti-resonance"?
   Because it is exactly opposite to series resonance.

6. Is there any change in the voltage when resonance is reached in a parallel alternating-current circuit?
   No

7. What does the line current equal in a parallel resonant circuit?
   Minimum current flow.

8. **What prevents the total current from becoming zero when resonance is reached in alternating-current parallel circuits?**
Resistance

9. **Explain the difference between the voltage at series and parallel resonance in an a-c circuit; the current; the impedance.**
See table below.

10. **What is the resonant frequency of a parallel circuit** consisting of a **capacitance of 400 micromicrofarads in one branch and an inductance of 240 microhenries in the other branch?**

$$f = \frac{1}{2\ /LC}$$

513 kilo Hertz

Answer to question 9:

	Series Resonant	*Parallel Resonant*
Voltage	*Equal to Line Voltage*	*Equal to Line Voltage* *Used as Zero Deg. Reff.*
Current	*Maximum*	*Maximum I Line*
Impedance	*Minimum Z = R*	*Maximum Z = QXL*

Check-up: (2-4-13)

1. What function of electricity makes the use of transformers possible?
   Mutual inductance

2. What is meant by the "magnetic circuit" of a transformer?
   The transformer core provides a circuit of low reluctance for the magnetic flux--the magnetic circuit is the path the flux lines take.

3. What is the phase relationship between the primary and secondary voltages of a transformer?
   The secondary voltage is 180 degrees out of phase with the primary voltage.

4. Is the magnetic circuit always through the core?
   No--because magnetic leakage occurs in a transformer.

5. What is the turns ratio of a transformer?
   The ratio of turns in the primary to the number of turns in the secondary.

6. What is meant by the "ratio" of a transformer?
   The voltage ratio is directly proportional to the turns ratio, while the current ratio is inversly proportional to the voltage ratio.

7. When the voltage of a circuit is raised to a higher value by use of a transformer, what effect does this have on the current of the circuit?
   For a given amount of volt-amps if you step up the voltage--you will step down the current.

8. What is meant by "ampere-turns?"
   The current in amps multiplied by the number of turns in a winding is called the ampere-turns.

9. **In an ideal transformer, what is the relationship between the power primary and the power developed by the secondary?**
Primary and secondary powers are equal.

10. **What constitutes the losses incurred in a transformer?**
Copper losses, flux losses (leakage), hysteresis loss, eddy current loss and saturation loss.

11. **What is hysteresis loss?**
The lagging behind the magnetizing force by the molecules in the core material. It is the energy that has to be supplied to the molecules to cause them to turn around and, in effect, try to catch up with the magnetic field which is constantly changing polarity--this energy expended is called the hysteresis loss of the core.

12. **What are eddy currents and how are they held to minimum in transformers?**
Eddy currents are small currents that circulate in the core induced by the alternating magnetic field. They are held to a minimum by using laminated cores. They still circulate in each lamination, however, causing a small I^2R *loss.*

13. **What is meant by transformer efficiency?**
Powerout divided by powerin = efficiency in percent.

14. **What is meant by saturated core?**
If current is increased in the winding flux, density in the core will normally increase until saturation; increasing the current produces very little increase in flux.

15. **What is an autotransformer?**
An autotransformer is a transformer where one of the windings, such as the primary, is common and in series with the other, i.e., some turns are common to both the primary and the secondary; they do not have separate primary and secondary windings which are electrically insulated from each other, as does the conventional transformer.

CLASSIFICATION OF TRANSFORMERS AND TYPES OF CONSTRUCTION

Check-up: (2-4-14)

1. **In power transformers, core type, what winding is usually found next to the core leg?**
   The low-voltage winding is normally next to the core and the high voltage winding, concentrically wound on the outside.

2. **Why is it necessary in power transformers to brace the windings well, especially near the ends of the windings?**
   This is necessary because under short-circuit conditions which cause a large current to flow, the forces between coils becomes tremendous, amounting to hundreds of thousands of pounds. If the coils are symmetrically arranged the forces within the transformer will be balanced except for the forces acting on the two end coils.

3. **How are the primary and secondary windings placed with relation to each other on the core?**
   The primary and secondary coils in the core type are wound one over the other with the low-voltage winding next to the core. This arrangement requires only one layer of high voltage insulation between the two windings. In the shell type it does not matter.

4. **How are the primary and secondary windings insulated from one another?**
   Insulation from winding to winding or from winding to core is made from casings and barriers bent around into shape. The turns are insulated from one another by wrappings of paper or cotton around the conductor itself.

5. **What materials are used for insulation?**
   The most efficient insulating material is mica, but press board, treated cloth or fibre, cotton or treated paper tape, fiberglass and transformer oil are most commonly used.

6. **How does oil rank as an insulator and what qualities has it that made possible its wide use in transformers?**
Oil is an excellent insulator and in transformers it serves a double purpose, carrying the heat from the winding to the surface of the tank and insulating the primary from the secondary.

7. **What kind of oil is used in transformers?**
Mineral oil, obtained from the fractional distillation of crude petroleum, and free from acids, alkalies and sulphur compounds, so as to prevent corrosion.

8. **What dielectric test should a good transformer oil stand?**
A good transformer oil should stand 22 kv @ 0.1 inch between terminals.

9. **Why must the insulation be made extra heavy on the end turns of high voltage transformers?**
To prevent voltage creepage.

10. **What is an inertaire transformer?**
Usually refers to a nitrogen-filled transformer. Nitrogen is an inert gas and will not sustain combustion or react with the oil or any insulation.

11. **What provisions are provided for the expansion of oil in transformers?**
(a) Expansion tanks--known as a conservator
(b) Holding the oil level low enough in the tank to allow space at the top for breathing

12. **Why is nitrogen used in transformers?**
Nitrogen is an inert gas, it will not sustain combustion. It will not cause oxidation of oil, it will not form water, so the oil in the transformer can be expected to remain dry, clean and clear.

13. **What does 55 degrees centigrade temperature rise mean?**

This means that the overall temperature should not rise more than 55 degrees centigrade above the surrounding cooling air when the cooling air is at a maximum permissible temperature of 40 degrees centigrade (104°F).

14. **What is a CSP distribution transformer?**

Completely self projected. They are equipped with overload and lighting protection.

15. **Calculate high-side and low-side amps of a single-phase transformer rated at 2,300/230/115 volts, 25 kva.**

10.8 amp @ 2,300 volts; 108.7 amps @ 230 volts; 217.4 amps @ 115 volts

16. **If a transformer is rated at 150 kva, what would be its kw rating at 80 percent power factor?**

kw = kva x powerfactor or kw = 150 x 0.8 = 120 kw

17. **Can a transformer be used at a lower than rated voltage?**

Yes

18. **Why are transformers rated in kva and not in kw?**

If the power factor remained 100% you could rate them in kw. The transformer windings are subjected to the volt-amperes which may not be the same as the watts.

19. **In some locations where oil-cooled transformers are considered a fire hazard, what other methods may be used to cool transformers?**

Dry type, air-cooled or askarel filled transformers. Askarels are noninflammable insulating liquids. Trade names are inteen and pyranol.

20. **The current input to the primary winding, with no load connected to the secondary winding, is usually from 2 to 5 percent of full-load current. This is normally called exciting current or charging current. What should be the charging current in a 2,500 kva, single-phase transformer rated at 11,000 to 2,400 volts?**

Full load rated current, low side is:

charging current low side $$\frac{2500\ \text{kva} \times 1000}{2400\ \text{volts}} = 1{,}041.7\ \text{amps}$$

2% of 1,041.7 = 30.8 amp and 5% of 1,041.7 = 52.08 amp

Full load rated amps high side is: $$\frac{2500\ \text{kv} \times 1000}{11{,}000\ \text{volts}} = 227.27\ \text{amps}$$

2% of 227.27 = 4.5 amp

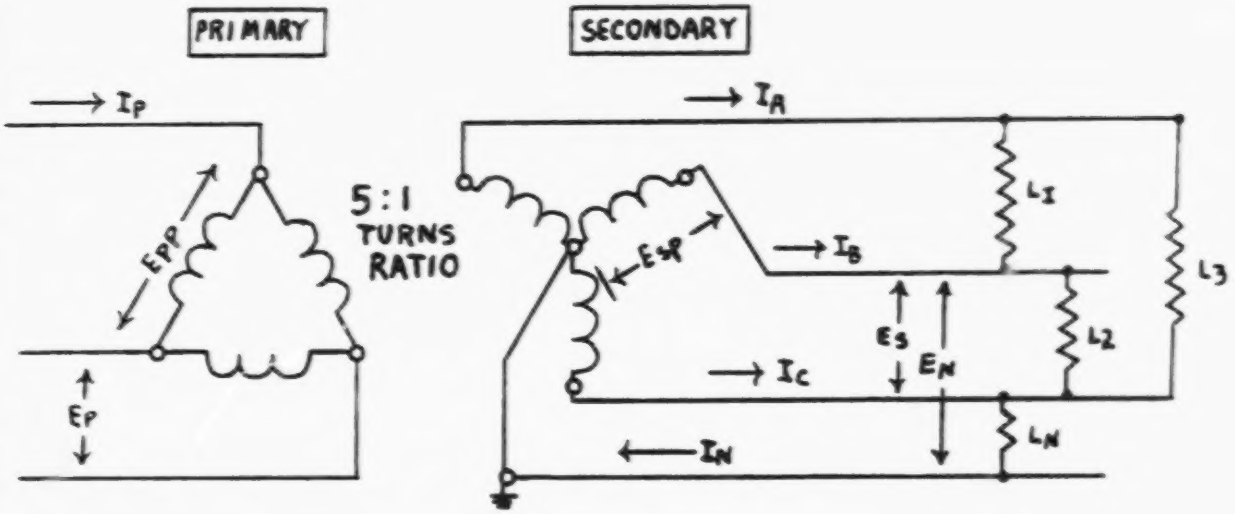
5% of 227.27 = 11.36 amp

∴ *charging current high side 4.5 amp to 11.36 amp*

Lesson 2-4-15

TRANSFORMER CONNECTIONS AND INSTRUMENT TRANSFORMERS

Check-up: (2-4-15)


PRIMARY
SECONDARY
I_P
E_{PP}
E_P
5:1 TURNS RATIO
I_A
E_{SP}
I_B
I_C
E_S
E_N
I_N
L_1
L_2
L_3
L_N

1. If E_{pp} = 500 volts, then E_p = *500 volts*
2. If E_{pp} = 865 volts, then E_s = *299.6 volts*
3. If E_p = 1045 volts, then E_{sp} = *209 volts*
4. If E_n = 120 volts, then E_{sp} = *120 volts*
5. If E_s = 480 volts, then E_n = *277 volts*
6. If E_n = 277 volts, then E_p = *1,385 volts*
7. If I_p = 100 amps, then I_{pp} (through E_{pp}) = *57.7 amp*
8. If load is balanced and I_p = 58 amps, then I_B = *167.4 amp*
9. If $L_1 = L_2 = L_3$ and $L_N = 0$, then $I_N = 0$. True or false? *False*
10. If $L_1 = L_2 = L_3 = L_N$, then $I_A = I_B = I_C$. True or false? *False*

Check-up: (2-4-16)

1. Why are instrument transformers used?
   Two reasons. To protect station personel from contact with high voltage. Also, to permit the use of instruments with a reasonable amount of insulation and current carrying capacity.

2. What are some advantages of a single-phase, three-wire circuit?
   This provides 240 volts for heating or appliances and also, two circuits of 120 volts for lighting and recepticals.

3. What is the difference in single and polyphase transformers and what advantage has each type over the other?
   A single phase transformer may be defined as one having only one set of primary and secondary terminals. In poly-phase there are two or more wound on a poly-phase core. A three phase occupies less space, weighs less, costs less than three single phase. A single phase is more versatile.

4. What polarity is most common in: (a) a power transformer; (b) a distribution transformer; (c) an instrument transformer?
   (a) subtractive (b) additive (c) subtractive

5. What is a transformer with a tertiary winding and what purpose does this winding serve?
   A transformer with a third winding. They are used when, for some reason or other, a third voltage is desired. Also used in wye-wye connected bank to suppress the third harmonics. When used for this purpose the winding must be connected delta.

6. What is a transformer with taps and what is its purpose?
   A transformer with taps means that provisions are made to change the turns ratio by connecting to various taps on the winding. Its purpose is to raise or lower voltage.

7. **Are the taps located near the end or in the center of the winding?**
The taps are located near the center--away from line surges.

8. **What problem is created by connecting a three-phase bank of transformers wye-wye and how is it overcome?**
Can cause telephone interference due to third harmonics. A tertiary winding is used and connected delta to provide a path for the third harmonics to circulate.

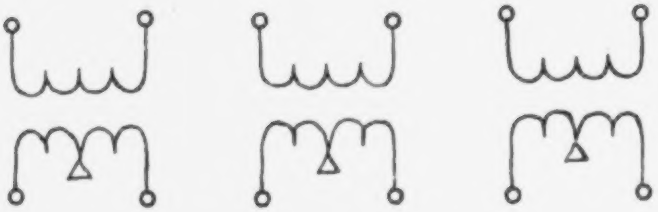
9. **How are transformer leads marked?**
The standard method uses the letter "H" for the high side and the letter "X" is affixed to the low side--tertiary winding terminals use the letter "Y".

10. **Explain what is meant by "additive" and "subtractive" polarity.**
If the transformer terminals H1 and X1 are adjacent, the transformer is said to be subtracting. If the transformer terminals H1 and X1 are placed diagonally from each other, the transformer is additive.

11. **List three requirements which should be observed if two transformers of equal kva capacity are to be connected in parallel so that they will share the load.**
(1) The voltage ratio must be the same.
(2) The tap settings must be the same.
(3) The % impedance must be between 92 1/2% and 107% of the other.

12. **Can transformer taps be changed under load?**
Not unless they are specifically built and equipped to do so.

13. **Make a connection diagram that shows how a transformer bank is connected for supplying a 240-volt, three-wire, three-phase system from a 2,400-volt, three-phase source. Use single-phase transformers with additive polarity, rated 2,400/240 volts at 100 kva. Mark the polarity of all transformer leads.**

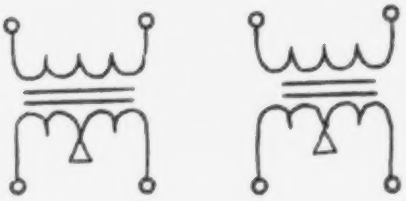


14. A balanced load of 200 kw at 0.80 lag power factor is supplied by the transformer bank in problem 13. What is the primary line current? The secondary line current?

$$I_{(pri)} = \frac{P}{1.732 \times E \times \cos e} = \frac{2000,000}{1.732 \times 2400 \times 0.8} = 60.15 \text{ amps}$$

$$I_{(sec)} = \frac{200,000}{1.732 \times 240 \times 0.8} = 601.5 \text{ amps}$$

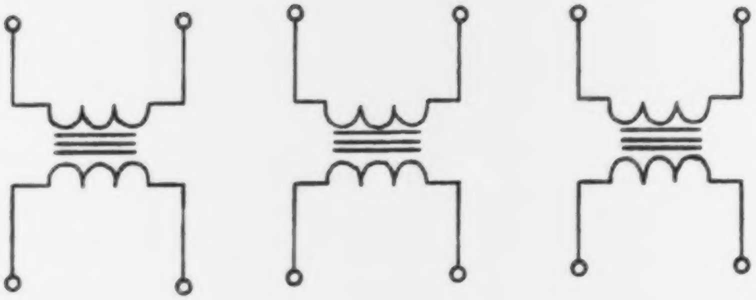
15. If one of the transformers in problem 13 were damaged and had to be removed, show how you would reconnect the remaining two, so as to maintain service.



16. What is the maximum balance load in kw of power factor 0.80 lag which could be connected to the transformer bank during the emergency described in question 15?

In this connection the units will have 86.6% of their rating, i.e., two 100 kva units have a bank capacity of 200 x 0.866 or 173.2 kva. With 80% power factor, then the kw load is equal to 173.2 x 0.80 or 138.5 kw.

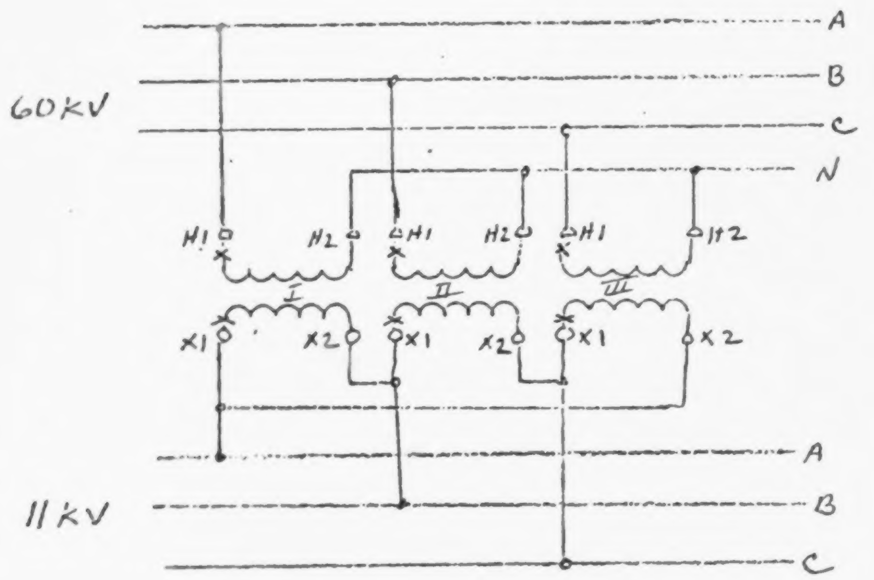
17. Make a connection diagram for three single-phase, 50 kva, 2,400/120-volt transformers with additive polarity to supply a four-wire, three-phase service of 120/208-volts that can supply both 120-volt single-phase lighting service and 208-volt, three-phase motor load. Show the high side of the bank connected to a 2,400/4,160-volt, three-phase primary.



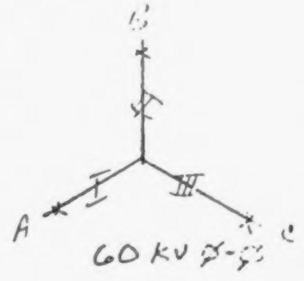
18. If the power factor of the load is 0.80, what is the maximum balanced three-phase load that sould be connected to the bank described in question 17?

kva x p.f. = kw. *3 x 50 x 0.80 = 120 kw.*

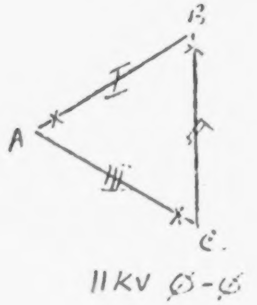
19. A three-phase, wye-connected transmission line has a voltage of approximately 60.5 kv across the three line wires and 35 kv from each line to ground. Make a connection diagram showing how to connect three transformers rated at 35,000 to 11,000 volts, 2,000 kva, with subtractive polarity so as to step the transmission voltage down to supply energy to an 11,000-volt, three-phase, three-wire distribution system.



60KV
A
B
C
N
H1
H2
H1
H2
H1
H2
I
II
III
X1
X2
X1
X2
X1
X2
11KV
A
B
C



B
I
II
III
A
C
60 KV φ-φ



B
I
II
III
A
C
11KV φ-φ

20. What is the line current on the secondary side when the transformer in question 19 is loaded to rated capacity? Neglect any losses.

$$I = \frac{P}{1.732 \times E \times \cos e}$$

Where E = φ-φ voltage

The current in the delta winding is = to line current/1.732

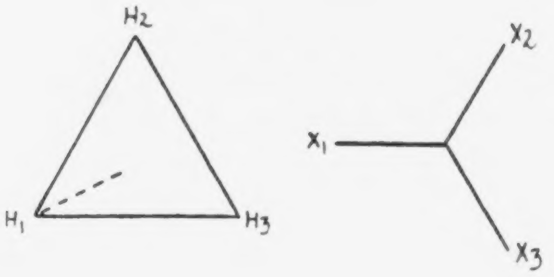
$$I = \frac{2{,}000 \times 10^3}{1.732 \times 11{,}000 \times 1}$$

I = 105 amps in secondary line.

21. What is the line current on the primary side when the transformer in question 19 is loaded to rated capacity? Neglect any losses.

$$I = \frac{P}{3 \times E \times Cos\ e} = \frac{2{,}000 \times 10^3}{3 \times 35{,}000 \times 1} = 19 \text{ amps, primary current.}$$

22.



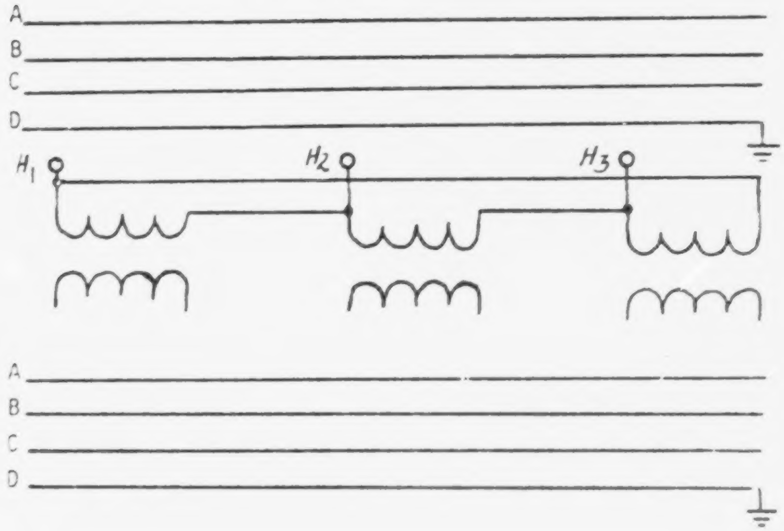
15,000 kva transformer
63,350/126,700 - 13,200/7200 volt

TAP	H.V.	L.V.
1.	66700	13200 volts
2.	65025	
3.	63350	
4.	61675	
5.	60000	

Complete the connection diagram for the above transformer if it is to be connected to a three-phase wye system having 57,000 volts across the three-phase wires and 33,000 volts from each phase to ground. The secondary is to supply energy to a three-phase wye distribution system having approximately 12,400 volts across the three-phase wires and 7,160 volts from ach phase to neutral. What tap is the transformer to be set on?

$$\text{Voltage ratio} = \frac{57{,}000\ v}{12{,}400\ v} = \frac{?}{13{,}200}$$

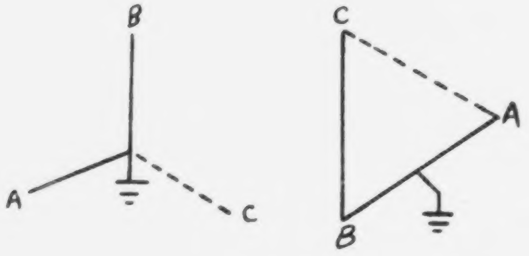
? = 60,600 volts: so set on tap #5.



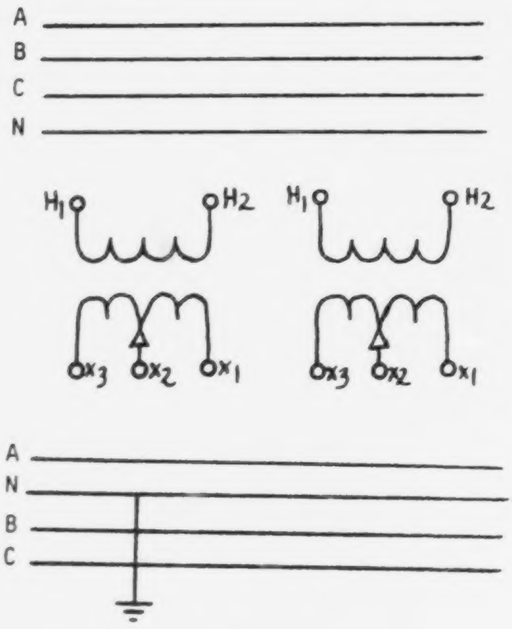
23. If, in question 22, the voltage is low and you are asked to change the taps, would you move the tap changer to a higher or lower tap number?
Lower the number of the tap to raise the secondary voltage.

24. If a transformer is rated at 150 kva, what would be its kw rating at 80 percent power factor?
Kw = kva x p.f. = 150 x 0.80 = 120 kw.

25. Complete the connections for a three-phase open-wye open-delta for 120/240 service as shown in the voltage diagram. This bank can then be used to supply large single-phase 240 volt and 120/240 volt loads with small amounts of three-phase loads.



210° ANGULAR DISPLACEMENT



Lesson 2-5-1

METER CONSTRUCTION AND METER MOVEMENTS

Check-up: (2-5-1)

1. **What are the two basic types of current meters?**

   (1) Electromagnetic

   (2) Thermal

2. **If the current through a coil is increased, what happens to the magnetic field around the coil?**

   The magnetic field is proportional to the amount of current.

3. **What is another name for the moving-coil meter?**

   D'Arsonval Meter Movement

4. **What are the three types of moving-iron meter movements?**

   (1) Radial vane type

   (2) Concentric-vane type

   (3) Plunger type

5. **What basic parts are common to most meter movements?**

   (1) A coil (2) A pointer (3) A scale (4) Pivots

   (5) Bearings (6) Springs (7) Retaining pins (8) A zero adjust

   (9) Damping

6. **Explain the difference between a hot-wire ammeter and a thermocouple meter.**

   A hot wire ammeter depends on the expansion of a wire when it is heated. The more current through a wire, the more it will expand. A thermocouple meter uses two dissimilar metals that when joined together produce an emf when their junction is heated and this junction is attached to a hot wire.

7. Explain why two springs are used in meter movements and how changes in temperature are compensated for.
   They are wound in opposite directions to compensate for the expansion and contraction that occurs as a result of temperature change.

8. Explain the principle and function of the zero-adjust screw.
   To set the pointer to zero with no current flowing.

9. If the current through a moving-coil meter doubles, by how much does the pointer deflection increase? Do moving-iron meters react the same? Explain any difference in the scales for the two meters.
   Pointer deflection also doubles; moving-iron meters react different; the pointer varies with the square of the current through the coil. Moving coil meter scales are linear while iron vane scales are square-law scales.

10. What is meant by damping in a meter? Why is it necessary?
    Because with very little friction of the rotating parts of a meter, the pointer has a tendency to overshoot its correct reading. The spring will pull it back and it will over shoot again slightly and so on. As a result the pointer tends to swing back and forth about the correct reading point many times before coming to rest. A meter movement must be damped to over come this problem. Damping can be thought of as a breaking action on the pointer.

Lesson 2-5-2

METER CHARACTERISTICS AND MULTIRANGE AMMETERS

Check-up: (2-5-2)

1. **Define meter sensitivity. What is its significance?**
   The amount of current necessary to cause the pointer to deflect full scale. It is the maximum current that can be sent through the coil without possible damage to the meter.

2. **Why can't the basic moving-coil meter measure a-c?**
   The meter cannot respond to the rapid changes. The effect is to cause the meter to read zero. With a rectifier added to change ac to dc it will make a fine meter for AC, however.

3. **Why is it desirable for a-c meter to indicate rms values?**
   rms or effective value is the most commonly used value.

4. **Why is a rectifier meter less accurate than a basic moving-coil meter?**
   Due to rectifier inaccurracies.

5. **What type of meter is used to measure high-frequency current?**
   A thermocouple meter.

6. **Why are external shunts used with meters designed to measure very large currents?**
   To prevent damage to the meter movement from the large current flow.

7. **What is a multirange meter? What is the advantage of such a meter?**
   A basic meter movement containing several shunts for various ranges of currents and/or voltages.

8. **What is meant by "observing polarity" when connecting a current meter?**
Current must flow in on the correct terminal. If current flows through the meter in the reverse direction, the pointer will be deflected down scale against the stop.

9. **Why should a current meter never be connected in parallel with a power source or load?**
A current meter is a very low resistance device. So many amps would flow through the meter that it would likely be destroyed.

10. **Should a 95-milliampere current be measured with the 0-10 milliamperes, 0-100 milliamperes, or 0-1 ampere range of a multirange meter? Explain your reason.**
Use the 0-100 milliampere range. For best accuracy and readability.

Lesson 2-5-3

VOLTMETERS--OHMMETERS AND MEGGERS (MEGOHMMETER)

Check-up: (2-5-3)

1. Explain how a current meter movement can be made to measure voltage.

   Because of the ohms law relationship, a current meter scale can be calibrated in volts and used to measure voltage.

2. Why are multiplier resistors used in voltmeters and shunt resistors used in ammeters?

   Multiplier resistors are used to extend the range of voltmeters and shunt resistors are used for the same purpose in ammeters and ohmmeters.

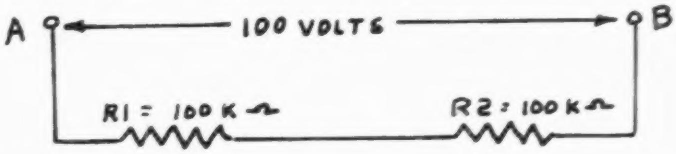
3. A zero to 1 milliampere meter movement has a coil resistance of 1000 ohms. What value of multiplier resistor is needed to measure 100 volts?

   99k ohms

4. What is meant by the ohms/volt rating of a voltmeter and what is the relationship between a meter's ohm/volt rating and the current required for full-scale deflection?

   The sensitivity of the meter--the higher this rating, the more sensitive is the meter, i.e., the less burden the meter has.

5.



   (a) Calculate the voltages that would exist across R_1 and R_2 in the circuit shown here.

   (b) If a 0 to 100 voltmeter with a sensitivity of 1,000 ohm per volt were to be connected across R_1, what would the voltmeter read?

   (a) 50 volts *(b) 33.3 volts*

6. If in question 5, a 0 to 100 voltmeter with a sensitivity of 20,000 ohm per volt is used: (a) What would the voltmeter read? (b) What would the voltmeter read if it is connected across points A and B? (c) When the voltmeter is connected across points A and B, what current flows through R_2?

   (a) 48.8 volts (b) 100 volts (c) .000512 amps or 512 microamp

7. (a) What is the basic difference between series and shunt ohmmeters?
   (b) What is the purpose of the xero-ohm set control?

   (a) In a series ohmmeter the resistances are measured by connecting in series with the movement and in the shunt ohmmeter the resistance to be measured is connected in parallel with the movement.

8. What might be the result of making resistance measurements on a circuit while the circuit is energized?

   Damage the ohmmeter.

9. What are wheatstone bridges used for? Must the circuit be deenergized before applying this device?

   To make extremely accurate resistance measurements. Yes, the circuit must be deenergized.

10. What is a megger and for what purpose is it used? Will it measure resistance? Explain.

    A megohmmeter--measures very high resistances used to test the quality of insulation on cables, motors and other electrical equipment.

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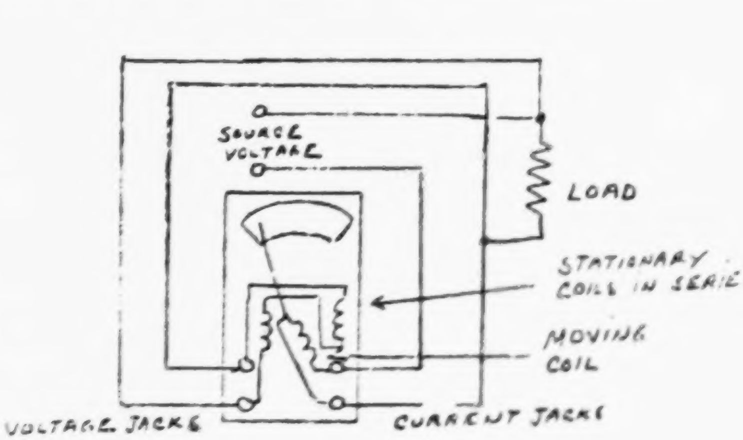
Check-up: (2-5-4)

1. **How else can power be measured, besides by use of a wattmeter?**
   Power can be calculated by multiplying current and voltage using a ammeter and voltmeter. $P = EI$,
   where current and resistance are known, $P = I^2R$ *or* $P = \frac{E^2}{R}$ *if the voltage and resistance are known.*

2. **What are the advantages of using a wattmeter?**
   Simplifys power measurements. In a-c circuits a wattmeter reads the true power regardless of phase angle.

3. **What is meant by a compensated wattmeter?**
   One that is compensated for its own power loss so that only the power dissipated in the circuit is measured.

4. **Draw the schematic diagram of a basic wattmeter.**



5. **If the wattmeter is not compensated and its power loss is not indicated on the scale, how can its power loss be determined?**
   Simply by disconnecting the load from the circuit, but leaving the wattmeter connected, the voltage coil then is in series with the current coil and the source current flows through both coils. The wattmeter will read its own power loss.

6. **What is a multimeter?**
Basically, a multimeter consists of a voltmeter, an ohmmeter and a ammeter contained in one case.

7. **What is a VTVM?**
Vacuum-tube voltmeter.

8. **What is the advantage of a VTVM over a regular voltmeter?**
VTVM's have very high ohms/volt ratings and provide more accurate voltage readings in high resistance circuits than do regular voltmeters.

9. **What is an r-f probe?**
A radio-frequency probe which contains a special crystal rectifier specifically designed to convert very high a-c frequencies to d-c.

10. **What else can a VTVM usually measure besides voltage?**
Most VTVM's are designed to measure resistance as well as voltage.

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Lesson 2-5-5

BRIDGE CIRCUITS AND VOLTAGE DIVIDER PROBLEMS

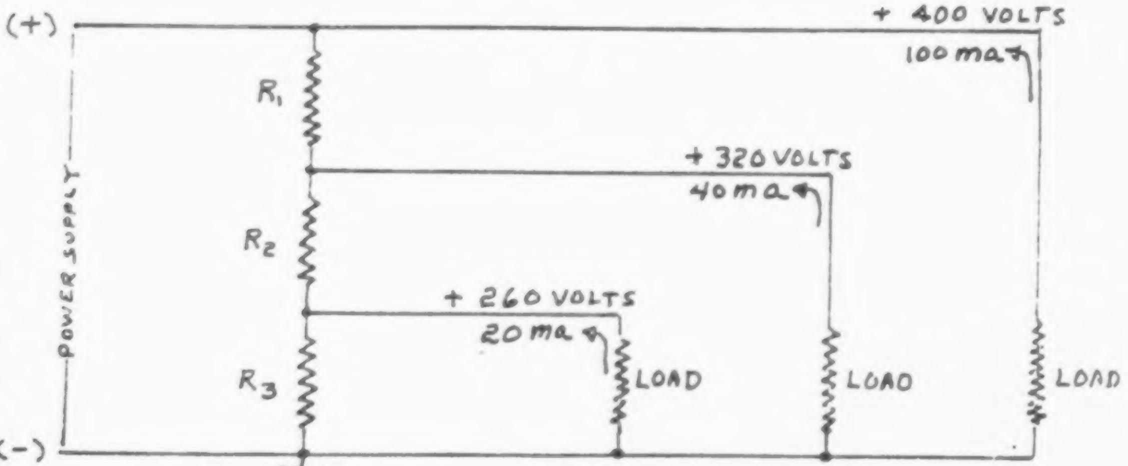
Check-up: (2-5-5)

1. A 0 to 50 microammeter has an internal resistance of 1,170 ohms. If this meter is shunted with a 130 ohm resistor, what must the meter reading meter be multiplied by, to obtain the correct value of current?
   10

2. A 0 to 1 milliammeter has an internal resistance of 55 ohms. What shunt resistance is required to extend the range of the meter: (a) 0 to 10 ma? (b) 0 to 50 ma? (c) 0 to 500 ma? (d) 0 to 2 amp?
   (a) 6.111 ohm (b) 1.122 ohm (c) 0.1102 ohm (d) 0.0275 ohm

3. The 0 to 1 milliammeter in question 2 could be made to operate as a voltmeter by adding a series resistor. What value of series resistance must be connected in series to give the meter a range of: (a) 0 to 10 volts? (b) 0 to 150 volts?
   (a) 9945 ohms (b) 149945 ohms

4. What are the values in ohms for the resistors R_1, R_2 and R_3 in the voltage divider circuit shown below? A total of 180 ma is drawn from the power supply?
   R_1 = 1 K ohms R_2 = 1.5 K ohms R_3 = 13 K ohms

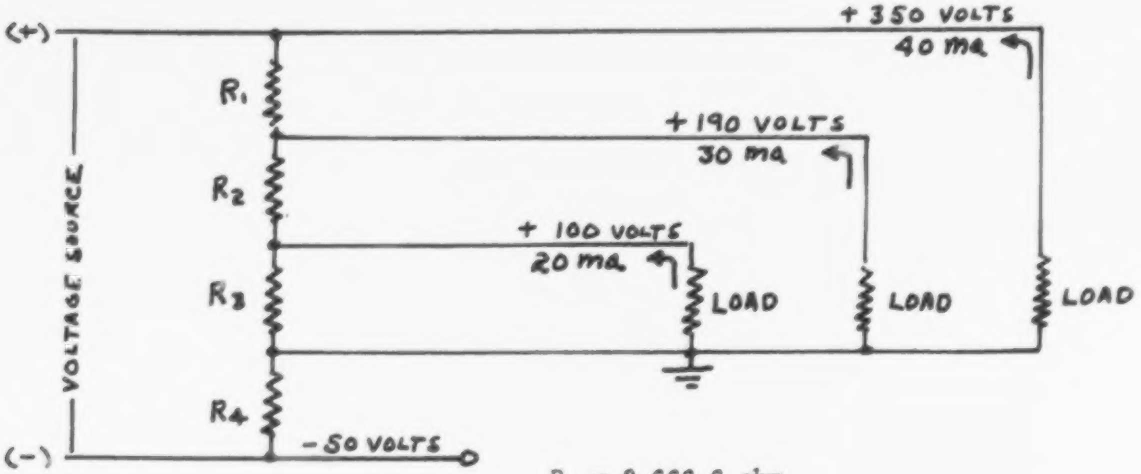


5. In the problem given for question 4, how much power is expended in:

(a) R_1 ?   (b) R_2 ?   (c) R_3 ?

(a) 6.4 watts   (b) 2.4 watts   (c) 5.2 watts

6. What are the values of the voltage divider resistors for the circuit shown below, if the bleeder current is 10 ma?


(+)
(-)
VOLTAGE SOURCE
R1
R2
R3
R4
+ 350 VOLTS
40 ma
+ 190 VOLTS
30 ma
+ 100 VOLTS
20 ma
LOAD
LOAD
LOAD
- 50 VOLTS

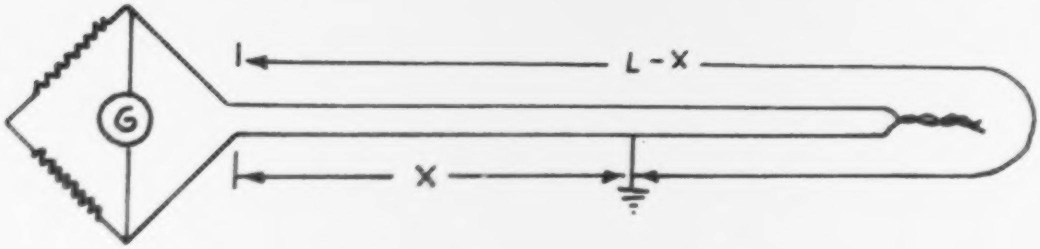
R_1 = 2,666.6 ohm
R_2 = 3 k ohm
R_3 = 10 K ohm
R_4 = 500 ohm

7. What wattage rating should be used for the voltage divider in question 6?

R_1 = 9.6 watts; R_2 = 2.7 watts; R_3 = 1 watt; R_4 = 5 watts

8. If the resistor R_4 became open circuited in problem 6, what would be the voltage between the negative terminal of the voltage source and ground?

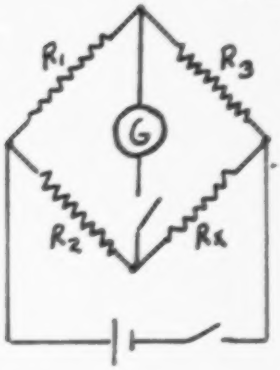
400 volts



9. The Murry loop shown above is set up to locate a ground that exists in one conductor of a lead-covered No. 14 pair. The pair is tied together at the far end. When the bridge circuit is balanced, R_1 = 18.7 ohm and R_2 =13.2 ohm. If the cable is 4,500 ft. long, how far from the test end is the grounded point?

1,862 feet

$$X = \left(\frac{R_2}{R_1 + R_2}\right) L$$



10. In the wheatstone bridge arranged as shown here; if R_1 = 0.001 ohm, R_2 = 1 ohm, and R_3 = 28.7 ohm, what is the value of R_x?

$$Rx = \frac{R_1R_3}{R_2}$$

Rx = .0287 ohm

Lesson 2-6-1

BATTERIES

Check-up: (2-6-1)

1. **Do storage batteries actually store electricity? Upon what action is the theory of all batteries based?**
   No--A Battery converts chemical energy into electrical energy. The chemical action that takes place between the electrodes and the electrolyte.

2. **What is a dry cell? What is a wet cell?**
   The dry cell contains a chemical paste while the wet cell uses a liquid chemical.

3. **Name three common types of dry cells. Can a dry cell be rejuvenated?**
   1. Zinc-carbon 2. Zinc-mercury also called alkaline cells
   3. The leclanche cell
   Although dry cells can not be recharged in the same way as wet cells--they can be rejuvenated.

4. **Will a storage battery produce a flow of electric current before it is charged?**
   No

5. **Will a storage battery, fully charged, remain in that condition if left on open circuit?**
   Yes for a considerable length of time.

6. Does the temperature have any effect on the output of a battery?
   Yes--lower temperature will reduce the output of a battery.

7. **What is the composition of the electrodes and electrolyte of an uncharged lead-acid cell?**
The cell consists of two electrodes, both made of lead sulfate ($PbSO_4$). *The electrolyte is for the most part distilled water with some sulfuric acid mixed.*

8. **What is the purpose of vent holes in secondary batteries?**
When the battery is charged by an electric current and starts a chemical reaction--the water electrolyte breaks down and, being H_2O, *gives off hydrogen and oxygen gas. This gas must be vented.*

9. **Can the condition of a storage cell be determined by checking the voltage of the cell on open circuit?**
No, not completely--if the cell is completely discharged its output voltage will fall to about 1.75 volts. When fully charged it should be about 2.1 volts for a lead acid cell.

10. **What damage can result from lighted matches or other sources of fires in a battery room?**
Hydrogen gas may be present and can result in a serious explosion.

Lesson 2-6-2

THE LEAD-ACID CELL AND OTHER VOLTAIC CELLS

Check-up: (2-6-2)

1. **What is the output voltage of a lead-acid cell at the instant the charging current is removed?**
   About 2.1 volts.

2. **What is the specific gravity of a fully-charged lead-acid cell?**
   A fully charged cell has a specific gravity of 1.280.

3. **Can a-c be used to charge a storage battery? If so, how?**
   No--not alternating current in the battery, but ac can be rectified (changed to d-c)and be used to charge batteries.

4. **What is sulfation?**
   When a battery is allowed to remain discharged for a long time, the lead sulfate becomes hard and brittle. The current capacity of the cell goes down. The sulfated area will not react properly with the electrolyte.

5. **Why must distilled water periodically be added to a lead-acid storage battery?**
   In charging, hydrogen and oxygen gas escape (boil away) and reduce the water level.

6. **In an alkaline secondary cell, is there a relationship between the specific gravity of the electrolyte and the state of charge of the cell?**
   No. The electrolyte does not change, it merely exchanges oxygen ions between the electrodes.

7. **What are the advantages of an alkaline cell over a lead-acid cell?**
   They require less attention and have a longer life.

8. **How is the current rating of a battery specified?**
They are rated according to the amount of current they can supply in a given amount of time. Ampere-hours.

9. **A battery has an ampere-hour rating of 80. What continuous current can it supply for ten hours?**
8 amps

10. **What is a solar cell? What is a thermoelectric cell? What is a photocell?**
A solar cell uses photovoltaic or thermoelectric cells as primary cells to keep a storage battery charged, utilizing light or the sun's rays as a source of energy. The thermoelectric cell uses heat energy at the junction of two dissimilar metals to cause electrons to flow. A series of the moelectric cells piled on top of one another is called a thermopile. There are several types of photo cells, usually referring to the photo conductive cell that is a variable resistor that permits more current to flow in a circuit when struck by light. A photovoltaic cell produces an emf when it is struck by light.

Lesson 2-6-3

BATTERY CIRCUITS

Check-up: (2-6-3)

1. If a 12 volt battery has an internal resistance of 0.1 ohm, what is its output voltage when supplying a current of 10 amperes?
   11 volts

2. What is the output voltage of four 12 volt batteries connected in series aiding? What is the output voltage if they are connected in parallel?
   (a) 48 volts (b) 12 volts

3. If a storage battery which has an efficiency of 75% is charged with 1,000 kw-hr of energy, what should be the amount of energy that can be recovered on discharge?
   750 kwh

4. What is the internal resistance of a cell which has a terminal voltage of 2.00 volts when discharging at a 12 ampere rate and the e.m.f. of the cell is measured at 2.05 volts?
   Resistance of the cell = .00417 ohm

5. The e.m.f. of a cell is 1.5 volts and its internal resistance is 0.2 ohm. When current is supplied to a circuit, the voltage drop across the internal resistance of the cell is 0.3 volt. (a) What is the terminal voltage? (b) How much current flows in the circuit?
   (a) 1.2 volts (b) 1.5 amps

6. A cell whose e.m.f. is 1.4 volts and internal resistance is 0.2 ohm is supplying 1.5 amp to a circuit. (a) What is the resistance of the external circuit? (b) How much power is lost in the cell?
   (a) 0.733 ohms (b) 0.45 watts

7. A high-resistance voltmeter reads 2.0 volts when placed across a cell that is connected to no other circuit. When the cell is delivering 5 amps to a circuit, the voltmeter indicates a terminal voltage of 1.1 volts. (a) What is the internal resistance of the cell? (b) What is the resistance of the external circuit?

(a) 0.18 ohms (b) 0.22 ohms

8. A cell that is delivering 0.25 amp has an internal resistance of 0.5 ohm. The e.m.f. of the cell is 1.6 volts. (a) What is the terminal voltage? (b) What is the resistance of the external circuit? (c) How much power is expended in the cell?

(a) 1.475 volts (b) 5.9 ohms (c) 0.03125 watts

9. Six cells are connected in series to a load of 8.4 ohms. Each cell has an e.m.f. of 1.5 volts, and the internal resistance of each cell is 0.1 ohm. (a) What is the circuit current? (b) How much power is expended in the battery?

(a) 1 amp (b) 0.6 watts

10. If the cells of problem 9 are connected in parallel, what is the circuit current?

0.1782 amp

Check-up: (2-6-4)

1. Why should storage batteries be charged from a d-c voltage source higher than the voltage of the battery? When connecting a battery charger to a battery, should the positive terminal of the battery be connected to the negative or positive of the charging circuit?

   If the voltage from the charger is too low, the battery will be discharged instead of charged. The battery voltage will be reduced to that of the charger. Chargers are connected positive to positive and negative to negative.

2. What is the chief use of storage batteries in power and substations and why are they used?

   Batteries provide the most dependable source of energy to trip or control station switchgear and equipment that may be critical to control.

3. What harm can be done by excessive or overcharging and how can the normal charging rate be determined?

   The life of the battery will be shortened. High current accelerates the chemical action that deteriates the electrodes.

4. What is the voltage per cell of a fully-charged storage battery?

   About 2.1 to 2.15 volts (no load) for the lead acid battery.

5. What is an equalizing charge?

   An overcharge given to the battery to insure that every plate in each cell is fully charged, that the specific gravity of all cells has leveled off.

6. What is the pilot cell?

   One cell that is chosen as an indication of the condition of the battery, usually one that is most convenient for inspection.

7. **Is the sediment which collects underneath the plates any cause for alarm?**
No, provided it accumulates at a very slow rate. The complete history of the cell is indicated by the sediment that collects beneath the plates.

8. **Electrolyte loses some of its water by charging of the battery and some by evaporation. Is it necessary, therefore, to add new electrolyte?**
No, not unless some should get outside the cell by carelessness.

9. **Why should hydrometers and other lifting tools used in a battery room be made of rubber, glass or be well protected with a rubber covering?**
Battery acid will not attack rubber or glass.

10. **Of what use is a soda solution in a battery room?**
To neutralize any battery acid that might be spilled.

Lesson 2-6-5

THE D-C GENERATOR

Check-up: (2-6-5)

1. **What serves as an automatic reversing switch on a d-c generator? What is its purpose; why is it necessary?**
   The commutator--it is to insure that the current always flows in the same direction. It transforms a-c to d-c. All generators are a-c generators and the a-c must be converted to d-c.

2. **What is meant by the neutral plane in a d-c generator? What would happen if the brushes were not positioned in the neutral plane?**
   If the position of the brushes is not in the neutral plane,a large current would flow in the short circuited coil and arcing would occur at the brushes. The neutral plane is theortically where the armature coils cut no flux lines and so have no voltage induced in them.

3. **How is the generator ripple reduced in a d-c generator?**
   By increasing the number of coils in the armature.

4. **Will increasing the number of turns in the armature coils affect the amount of ripple in the output voltage of a d-c generator?**
   No, it will increase the voltage.

5. **If a generator has eight commutator segments, how many separate armature coils does it have?**
   Four

6. **How can you control--increase or decrease the voltage output of a d-c generator?**
   With a fixed number of turns on the armature coils--then you can increase or decrease voltage by raising or lowering the field current--or, increase or decrease speed.

7. **Does the number of armature coils affect the number of brushes required for a d-c generator?**
No, it will affect the amount of ripple in the output voltage.

8. **Can alternating current be used as a field for a d-c generator? What type of current must be used?**
No, a-c cannot be used--only direct current is used in the field.

9. **What is excitation current? Explain the difference between separately excited d-c generators and self-excited generators.**
When the field winding on a generator is an electromagnet, current must flow through it to produce a magnetic field. This current is called the excitation current. When this current comes from a separate, external d-c voltage source, the generator is said to be separately excited. It can come from the generators own output, then it is said to be self-excited.

10. **Why does a series generator have poor voltage regulation?**
Changes in load current greatly affect the generator output voltage--the field is in series with the load.

11. **Why are shunt generators said to be self-protective?**
Because the output voltage will drop as load increases. If the load should be shorted, the voltage drops to zero.

12. **What type of d-c generator has its field connected in parallel with its armature/what type of generator has its field connected in series with its armature and what is the generature called that has both a winding connected in series and a second winding connected in parallel?**
(a) The short generator *(b) The series generator*
(c) Compound generator

13. **What is meant by the reference to "build-up" of a d-c generator? Is this necessary in separately excited generators?**
When a self-excited generator is started, it takes some time for it to reach its rated output because most of the magnetism of the iron is lost when the generator is shut down and it takes some time to build it up

starting with only residual magnetism. No--not in separately excited generators.

14. **In a compound generator, do the magnetic fields of the two windings aid or oppose each other?**
    The two fields aid each other.

15. **Which type of generator will supply the more stable voltage for varying load conditions, series, shunt or compound wound generators?**
    Compound wound generators

Lesson 2-6-6

D-C GENERATOR CONSTRUCTION

Check-up: (2-6-6)

1. When a generator has a large number of poles, is the total number odd or even? How are the field coils mounted--do they rotate or are they fixed?

   (a) Even (b) Alternate north-south-north-south-etc.

   (c) They are fixed.

2. What is armature reaction--what causes it--why can it be troublesome?

   A reaction caused by the magnetic field built up around the armature by the load current. This reaction shifts the neutral plane in the direction of rotation and results in poor commutation.

3. What are interpoles--what reaction do they correct for?

   Interpoles are auxiliary poles built into commutating pole generators--they produce a flux at such location so as to eliminate brush sparkling.

4. What are compensating windings and what is their purpose?

   Compensating windings are small series windings set in the main pole pieces--they are in series with the armature winding and their current and magnetic fields are opposite in direction to those of the armature coil. They eliminate armature reaction.

5. Name the two types of windings used on an armature.

   Lap windings and wave windings. Lap windings sacrifice voltage output for current capacity. Wave windings sacrifice current-carrying capacity for high voltage.

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6. **Why is the armature core and the field winding core of a generator laminated? What material is generally used for this core?**
The armature core is made of many thin pieces of soft steel called laminations--coated with an insulating varnish to reduce loss due to eddy currents that are induced in a conducting material when it cuts through magnetic flux lines.

7. **What are the pole pieces--what is their function--why are pole pieces shaped to fit the curvature of the armature?**

The field windings or coils are wound around the pole pieces. These form the electromagnets used to produce the magnetic field.

8. **What are commutator bars made of? Must the commutator and brushes of a generator be lubricated? Why?**
Commutators are made out of copper. No lubrication should be used between the brushes and the commutator. The graphite in the brushes provides self-lubrication.

9. **What characteristic has carbon that makes a favorable material for use as brushes on d-c machines?**
The resistance of carbon decreases with any rise in temperature. Brushes are made from small blocks of a carbon and graphite compound designed to wear out faster than the commutator.

10. **What is the most common method of dissipating the heat generated in a d-c generator?**
By means of air holes and a fan--the fan is mounted on one end of the armature shaft. When the armature rotates, the fan forces air through the airholes to carry the heat from inside the generator to the outside of the housing.

Lesson 2-6-7

THE A-C GENERATOR

Check-up: (2-6-7)

1. **Name two advantages of the rotating field type alternator as compared to the rotating armature type a-c generator.**

   With a stationary armature the output leads can be directly connected to an external circuit without the need of brushes or slip rings. Therefore, the current and voltage can be much higher--insulation is easy to provide for.

2. **In an a-c generator, what is the rotor? The stator? What part produces the magnetic field in most alternators?**

   (a) The portion of an a-c generator that rotates is called the rotor.
   (b) The stationary portion is called the stator.
   (c) The rotor is the rotating field winding.

3. **Are slip rings required on a stationary-armature generator? What is the function of the slip rings--do they carry a-c current or d-c? Why are brushes used?**

   Yes--slip rings and brushes are used to connect the rotating field winding to an external source of d-c. The brushes are made from a carbon and graphite compound.

4. **How does the speed of rotation affect the frequency of the voltage generated? What is the relationship of frequency, number of pairs of poles and the rpm in an alternator?**

   The output frequency of an a-c generator is equal to number of revolutions per second times the number of pairs of poles. For a generator with a given number of poles, the higher the speed of the generator--the higher will be the frequency.

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5. **What advantages do a-c generators have over d-c generators?**
A-C generators do not have commutaters and so in this respect are superior to d-c generators. Stationary-armature generators can rotate at very high speed and are more adaptable to various prime movers (steam, water, engines, etc.).

6. **Why do a-c generators have poorer regulation than d-c generators?**
As load increases, there is not only an IR drop in the generator but the output voltage drops due to an IXL drop caused by the a-c current flowing through the inductance of the winding. The output voltage will vary with both changes in load and changes in power factor. A-C generators are separately excited, thus load current changes do not effect field current.

7. **What are motor-generators used for?**
Used to change electricity from one voltage or frequency to another voltage or frequency, or to convert a-c to d-c or d-c to a-c. A motor generator used to change d-c to a-c is sometimes called a converter.

8. **Why are a-c generators normally not rated in watts or kilowatts?**
Power consumed depends on the power factor of the load so they are rated by apparent power.

9. **An a-c generator has a rating of 20 kilovolt-amperes and an output of 2 kilovolts. What is the maximum current it can safely deliver?**
10 amps

10. **What is the function of a dynamotor? What is a converter?**
A dynamotor is used to convert low d-c voltages, usually supplied by batteries, to high d-c voltages. They are always contained in a common housing and are frequently used with communications equipment.

[illegible]

Check-up: (2-6-8)

1. Most three-phase alternators used in modern power generating stations are wye connected. The output terminals are commonly labled T1, T2, T3. The sequence of the voltages for correct rotation is phase 1, 2, 3. If the sequence of voltages was found to be 1, 3, 2; would they still differ in phase by 120 degrees?

   Yes

2. The output voltage of a three-phase, wye-connected generator is 13.8 kv. The generator is delivering 25 megawatts and 10 metavars to the power system. What amount of amperes would you expect to find in each phase (stator coil) of the generator? Assume a balanced load.

   $KVA = \sqrt{KW^2 + KVAR^2}$ $\qquad$ $I = \dfrac{KVA \times 1000}{1{,}732 \times E}$

   $KVA = 26{,}925.8$ $\qquad$ $I = 1{,}126$ *amps*

3. Assume we have two alternators operating in parallel and it is desirable the load should be shared between them. With d-c generators, the proper division of load between machines is obtained by changing the field excitation of the two generators until the load is shared between them. How are a-c generators adjusted so as to share the load?

   By changing the input to the prime movers of the machines--not by changing their field excitation.

4. A three-phase, wye connected generator is rated for 24 kv and 1200 amperes. Determine the kva rating of the generator.

   $KVA = \dfrac{(IE)(1{,}732)}{1{,}000} = \dfrac{1{,}200 \times 1.732}{1{,}000}$

   $KVA = 49{,}881.6$ or 49.88 MVA

5. If the generator in question 4 is delivering rated current to a load with 80% lag power factor, what is the megawat output of the generator?

$$KW = \frac{IE \times 1.732 \times pt.}{1,000}$$

MW = 39.905 or KW = 39,905.28

6. Explain what happens when an attempt is made to shift the kw. load between alternators by changing the field excitation. Assume the governor control to the two prime movers is not changed.

The power output of each generator remains practically the same; however, the current output of each generator will increase and neither machine will operate at unity power factor. The generators will either take in VARS or put out VARS.

7. A three-phase, delta connected generator is rated at 10,000 kva., 11,000 volts and 60 hertz. What is the full-load current at unity powerfactor?

$$I = \frac{KVA \times 1000}{1732 \times E} = 525 \text{ amp}$$

8. In question 7 the generator efficiency is 86%. What must the horsepower input from the prime mover to the generator be if the generator is generating at full rating?

$$\%\ eff = \frac{output}{input} \qquad input = \frac{10,000\ KV}{0.86} = 11,627.9\ KVA$$

$$H.P. = 0.746 \times 11,627.9 = 8,674.4\ H.P.$$

9. List four separate conditions that must be met before an alternator can be synchronized to parallel with another a-c generator.

(1) If a 3Ø machine--the phase sequence must be the same.

(2) Their output voltages must be the same.

(3) Their frequencies must be the same.

(4) Their output voltages must be in-phase.

10. A three-phase, wye-connected generator is rated at 50,000 kva and 13.8 kv. What is the voltage rating of each of the three windings? When 1400 amps of load current flows in each phase winding, how much load current will flow in the lines, out to the load?

(a) 7.97 kv (b) 1400 amps in each line

Lesson 2-7-1

D-C MOTORS

Check-up: (2-7-1)

1. **What important role does the commutator play in the operation of the d-c motor?**
   It reverses the current direction so that the magnetic field will keep the armature turning in the same direction.

2. **What are the effects of "armature reaction" in a motor? In what direction is the neutral plane shifted by armature reaction?**
   It shifts the neutral plane opposite to the direction of rotation of the armature and results in poor commutation.

3. **What is the relationship between the number of commutator segments and armature windings?**
   You only need one segment per loop or coil as they are normally called. If an armature has 16 coils--there will be 16 segments on the commutator.

4. **What characteristic has a shunt-wound motor that makes it suitable for driving certain types of machinery?**
   It can hold a constant speed while serving a changing load.

5. **How may the speed of a shunt-wound motor be varied? What controls the speed of a series-wound motor?**
   (a) By using a rheostat control in the field--an increase in field current will reduce motor speed because it increases cemf. By using a rheostat in armature circuit--decreasing armature current slows the motor down.
   (b) The load with no load series motors have a tendency to run away.

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6. **To what types of load is a series-wound motor especially adapted?**
High starting torque against heavy loads that remain coupled to the motor such as hoists, cranes, etc.

7. **What is a compound-wound motor and what advantages does it have over both shunt-and series-wound?**
A shunt motor with a series field--or a series motor with a shunt field. They are designed for use where more nearly constant speed is desired under widely varying loads than can be obtained from a shunt motor.

8. **What is "counter emf"? Why is a resistor necessary for starting a d-c motor?**
CEMF is generated when the armature begins to turn. CEMF acts as an automatic current limiter, it opposes the line voltage and since the armature resistance is very low--frequently less than one ohm--a resistance is used in series to limit the current through the armature until the armature begins to turn and a induced CEMF is built up.

9. **Why will a motor speed up when the strength of the field decreases?**
A reduced field current means reduced flux which means reduced CEMF and thus more armature current. A shunt motor will tend to run away if the field winding opens.

10. **How do you reverse the direction of rotation on a d-c motor?**
Reverse either the field or the armature current, but not both at the same time.

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Lesson 2-7-2

STARTERS AND CONTROLLERS

Check-up: (2-7-2)

1. **Why do all d-c motors require some type of starter or controller?**
   Starters limit the current to a safe value until the motor generates sufficient CEMF. Otherwise, the high starting current could possibly cause brush and commutator burns and possibly cause the armature winding itself to burn open.

2. **How are manual starters classified?**
   They are classified (1) by how they preoperated; either manual or automatic; (2) by the way they are built: as face plate and drum types; (3) by how they are enclosed: drip proof, water tight, etc. They are also classified according to the number of terminals that must be connected to the motor: as two point, three point, and four point.

3. **Explain the difference between a motor controller and a starter.**
   A starter serves no other function once the motor is brought to operating speed. A controller combines the functions of starting and variable speed control.

4. **What kinds of motors are controllers normally used with?**
   Mostly with shunt and cumulative compound motors.

5. **How may the speed of a compound wound motor be varied or controlled?**
   With the use of a separate field rheostat in series with the shunt field.

6. **What is meant by "dynamic braking" and how is it accomplished?**
   In dynamic braking, the armature of the motor is disconnected from the power supply and the load will drive the motor as a generator. The generator action is loaded through resistance banks which are connected to the armature. Regenerative braking cannot be used to stop a motor-- it will produce braking action only when the load overhauls the motor and

drives the motor at a speed above the speed--load characteristic of the motor. Dynamic braking is frequently used on elevators, hoists, etc.

7. When are drum controllers most useful?
Where frequent starting and stopping, reversing and speed changes are required.

8. With the above-and-below-normal speed controller, when is the armature resistance changed? The field resistance?
For above normal speed--resistance is cut in series with the field. For below speed-resistance is inserted in series with the armature.

9. What kind of protection do you have with an automatic controller?
Under voltage and overload protection.

10. What extra motor control does a drum controller give?
Forward and reverse.

Lesson 2-7-3

A-C MOTORS

Check-up: (2-7-3)

1. **What are two general types of alternating-current motors?**
   Induction motors and synchronous motors.

2. **Are a-c motors more or less troublesome to operate than d-c motors?**
   A-C motors are easier to start, cheaper to construct and for all but special applications are less troublesome than d-c motors.

3. **What specific types of induction motors are there?**
   Squirrel cage, wound-rotor, consequent pole. There are also single phase and three phase. For single phase there are capacitor-start-induction run; capacitor-start-capacitor run; split phase; a-c series; repulsion run; and shaded pole.

4. **A three-phase motor operates on what principle?**
   A rotating megnetic field--each phase supplies one of three separate pair of poles and each rotating phase is 120 degrees apart, this causes the stator's magnetic field to rotate.

5. **Just what is meant by motor "slip"?**
   An induction motor cannot run at synchronous speed. It must slip to cut the fields lines of force so it runs at less than synchronous speed.

6. **What is a "squirrel-cage" winding?**
   A winding used on the revolving rotor for a three phase induction motor. It is not so much of a winding but consists normally of copper bars mounted near the surface of the rotor which are welded to two copper endsprings.

7. **What other types of winding are used on rotors of induction motors?**

   Wound rotor motors--they have lower starting current than squirrel cage motor. Also have a higher starting torque.

8. **How may the speed of an induction motor be controlled or varied?**

   Best control is obtained by using a variable-speed wound-rotor motor so resistance can be cut in or out by means of slip rings (three are required) and brushes.

9. **Describe the construction of a synchronous motor.**

   It is similar in construction to a three-phase a-c generator in that its revolving field must be separately excited from a d-c source. It has a laminated stator with three armature windings, brushes and slip rings.

10. **Why is it that a synchronous motor cannot be started by applying three-phase a-c to the starter?**

    The synchronous motor develops no torque when power is first applied--the stator polarity alternates as the magnetic field rotates so the rotor is first attracted in one direction and then alternately repelled--the net result is that the rotor stands still.

11. **On what kind of loads are synchronous motors used?**

    Where a constant speed is desired regardless of motor load. The synchronous motor gets its name from the term synchronous speed.

    $$RPM = Speed = \frac{120 \times frequency}{number\ of\ poles}$$

12. **How can synchronous motors be designed to be self starting?**

    By providing another set of windings so it can be started as an induction motor. Sychronous motors are never started with the d-c field circuit energized.

13. What type of current is used to magnetize the rotors of large synchronous motors?
Direct current. In some installations, electronic rectifiers supply the d-c excitation current.

14. How can the use of synchronous motors improve a plant's power factor?
By overexcitation of the rotor (increasing the d-c field current) they will take phase-leading current from the power line like a capacitor. The synchronous motor is then said to have a leading power factor.

Check-up: (2-7-4)

1. On a 60-cycle system what will be the speed in rpm of a 12-pole motor?

   $$\text{rpm} = \frac{120 \times \text{freq}}{\text{No. of Poles}}$$

   600 rpm

2. How are motors wound so they may be used on more than one service voltage? For example 240 or 480 volt?
   Each single-phase winding consists of two sections with leads brought out to the terminal box of the motor. The two sections are connected in parallel for 240 volt supply or in series for the 480 volt operation.

3. How may the rotation of a three-phase induction motor be changed?
   By interchanging any two of the three line wires feeding the motor.

4. Will a three-phase series motor continue to run at normal speed if one fuse blows?
   Yes, if the three-phase motor is already operating at rated speed, but it will operate with considerably reduced capacity and if the motor is shut down it will not start as a single phase motor.

5. What is meant by the term torque?
   Torque determines the energy available for doing work. It is the basic twisting force of a motor and is measured in pound-feet.

6. What is meant by a single-phase series motor and where are they used?
   This is an a-c motor similar to the d-c series motor especially designed for a-c operation. The ordinary d-c series motor fails to operate satisfactorly on a-c.

7. What is a repulsion motor and in what way is it similar to a d-c motor?
   The repulsion motor uses a drum wound armature, a commutator, and brushes very much like those found in the d-c motors. However, the brushes are shorted to each other. This motor is for operation on single phase circuits.

8. **Is there any electrical connection between rotor and field of an induction motor?**
No. The only power supplied to the rotor is through electromagnetic induction from the stator.

9. **What determines the speed of an induction motor?**
The synchronous speed is determined by the number of poles and the frequency. The true speed is something less expressed as a percent slip, varying from 2 to 5 percent.

10. **What will be the speed of a single phase two-pole motor on a 60-cycle circuit?**
3600 rpm

11. **Describe the construction of a repulsion-induction motor rotor.**
The repulsion-induction motor combines a squirrel cage winding beneath the slots of the armature and a winding placed in the slots and connected to a commutator using shorted brushes. It is really two motors in one as both windings are always in operation.

12. **What is a synchronous condenser? For what is it used?**
A synchronous motor used to improve power factor.

13. **Name two ways in which capacitors are used on single-phase induction motors.**
(1) In capacitor-start, induction-run motors, where the starting winding is connected in series with the capacitor while starting and a centrifugal switch opens and disconnects the start winding and capacitor from the line.
(2) The capacitor-start capacitor-run motor is similar to the above except that the starting winding and capacitor are left in the circuit at all times the motor is on the line.

14. State the most common use for synchros or "Selsyn" motors.
They are used for remote indicating the position of transformer tap connections, generator rheostats, gate or intake valves, etc.

15. What effect does low voltage have on the operation of a-c motors?
Low voltage (below 10 percent) results in an increase in current, an increase in power factor, an increase in slip and a decrease in torque.

ELECTRICAL PRINT READING

Check-up: (2-8-1)

1. Place the correct wire group letters in the blank circles to match up the wire groups.

2. Complete the connections to the CT terminal blocks, observing the correct polarity and ratio as is on the one-line schematic and three-line wiring diagram.

3. Label the wires at the CT terminal blocks - C1, C2, C3, and C0 to correspond to A, B, C, and common (i.e., the wire that carries A-phase current should be labeled C1, the wire that carries B-phase current should be labeled C2, etc.).

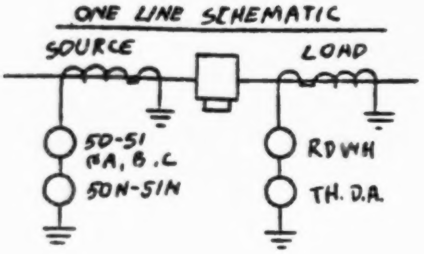
4. On page 28 is a three-line schematic. The breaker is shown at the bottom of the page, the meters and relays are shown above. You will find brackets numbered 1 to 32. These brackets are to be used to identify the CT terminal block terminal designations, the type FT-1 test switch letters, meter terminal numbers, or relay terminal numbers. Refer to the wiring diagrams on page 27.

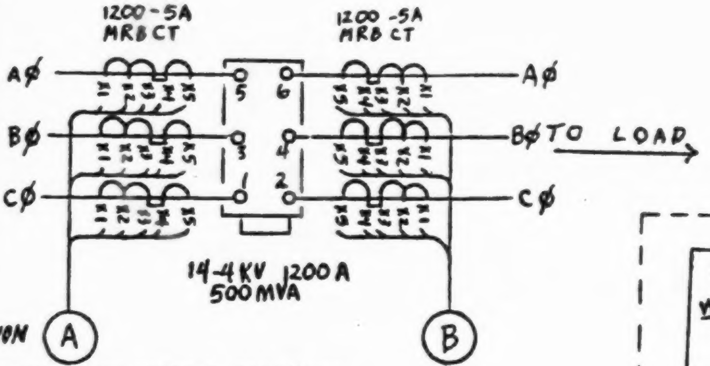
PRINT READING EXERCISE:

label C1, C2, C3, CO for both sets, observe the polarity of the connections as per the one line diagram.

1200-5A MRCT	
TAPS	RATIO
X2-X3	100
X1-X2	200
X1-X3	300
X4-X5	400
X3-X4	500
X2-X4	600
X1-X4	800
X3-X5	900
X2-X5	1000
X1-X5	1200

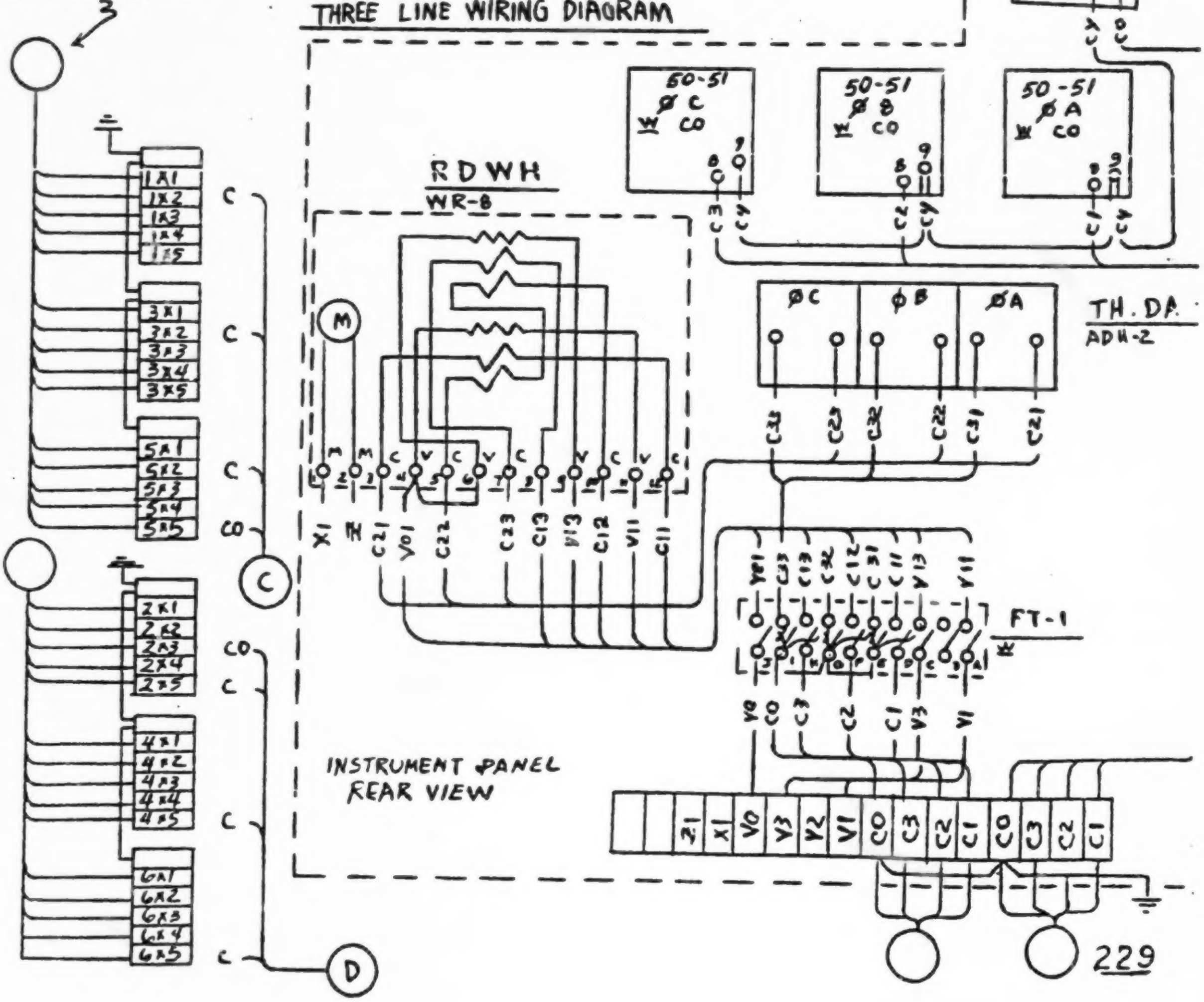
ONE LINE SCHEMATIC


SOURCE
LOAD
50-51
ØA, B, C
50N-51N
RDWH
TH. D.A.


1200-5A
MRB CT
1200-5A
MRB CT
AØ
BØ
CØ
AØ
BØ TO LOAD
CØ
X1
X2
X3
X4
X5
5
6
3
4
1
2
14.4KV 1200A
500MVA
A
B

PLACE WIRE GROUP IDENTIFICATION IN BLANK CIRCLES

THREE LINE WIRING DIAGRAM


50-51
N
W CO
8
9
C4
C0
50-51
Ø C
W CO
50-51
Ø B
W CO
50-51
Ø A
W CO
8
9
C3
C4
C2
C4
C1
C4
RDWH
WR-8
M
ØC
ØB
ØA
TH. DA
ADH-2
C33
C23
C32
C22
C31
C21
1X1
1X2
1X3
1X4
1X5
3X1
3X2
3X3
3X4
3X5
5X1
5X2
5X3
5X4
5X5
2X1
2X2
2X3
2X4
2X5
4X1
4X2
4X3
4X4
4X5
6X1
6X2
6X3
6X4
6X5
C
C
C
CO
C
CO
C
C
c
C
D
X1
X1
C21
V01
C22
C23
C13
V13
C12
V11
C11
V01
C33
C13
C32
C12
C31
C11
V13
V11
FT-1
V0
C0
C3
C2
C1
V3
V1
INSTRUMENT PANEL
REAR VIEW
Z1
X1
V0
V3
V2
V1
C0
C3
C2
C1
C0
C3
C2
C1
229

Print Reading Exercise: Check-up: (2-8-1) Note that the same C.T. connections are shown below on a three line schematic.

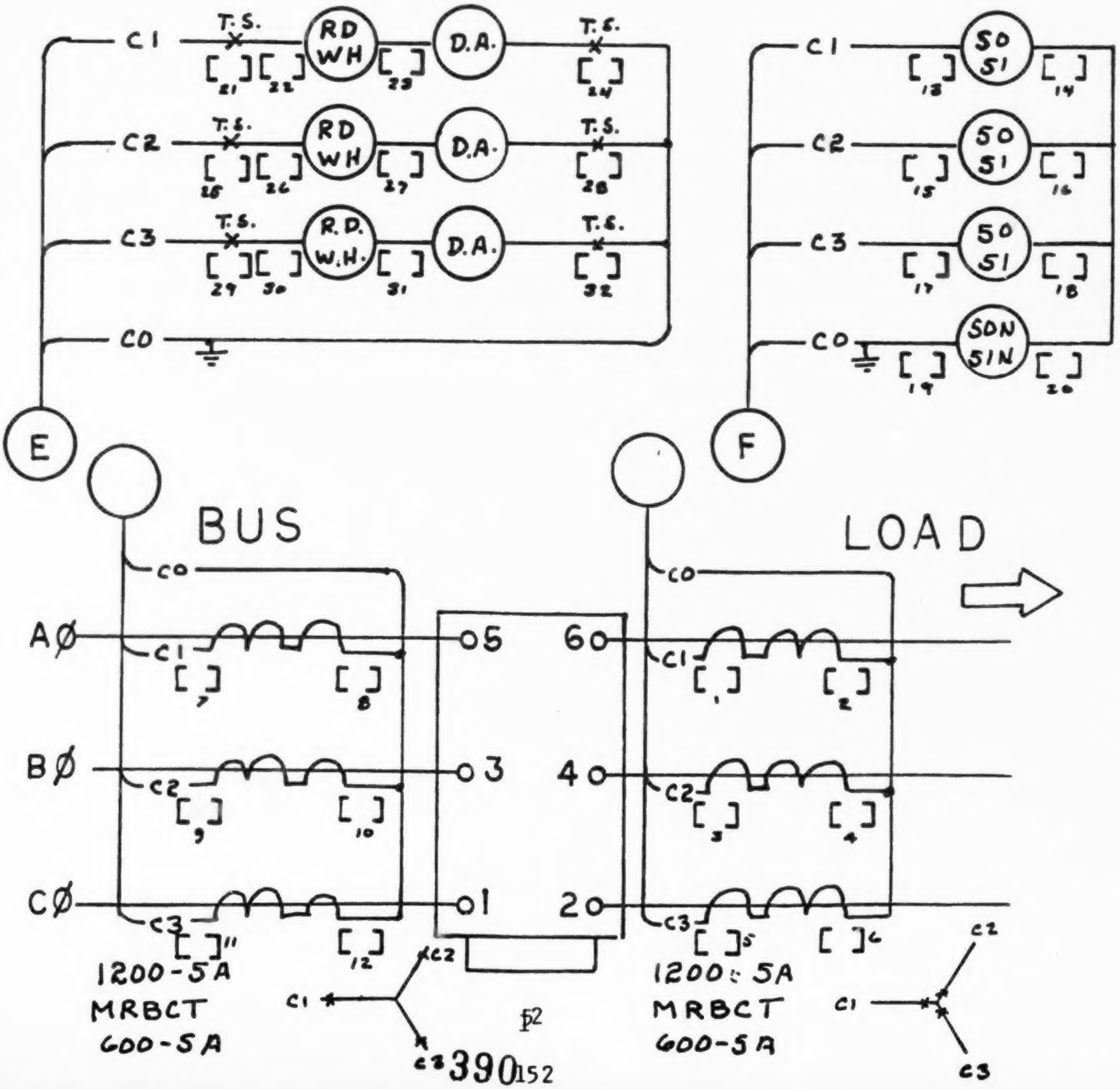
Identify the C.T. terminal block connections used in this application by placing the correct C.T. terminal in the brackets adjacent to the C.T. secondary wire.

Place the wire group identification letter in the correct circles.

Identify the relay terminals by placing the correct number of the terminal in the brackets adjacent to the relay. In the same manner identify the RDWH meter terminals.

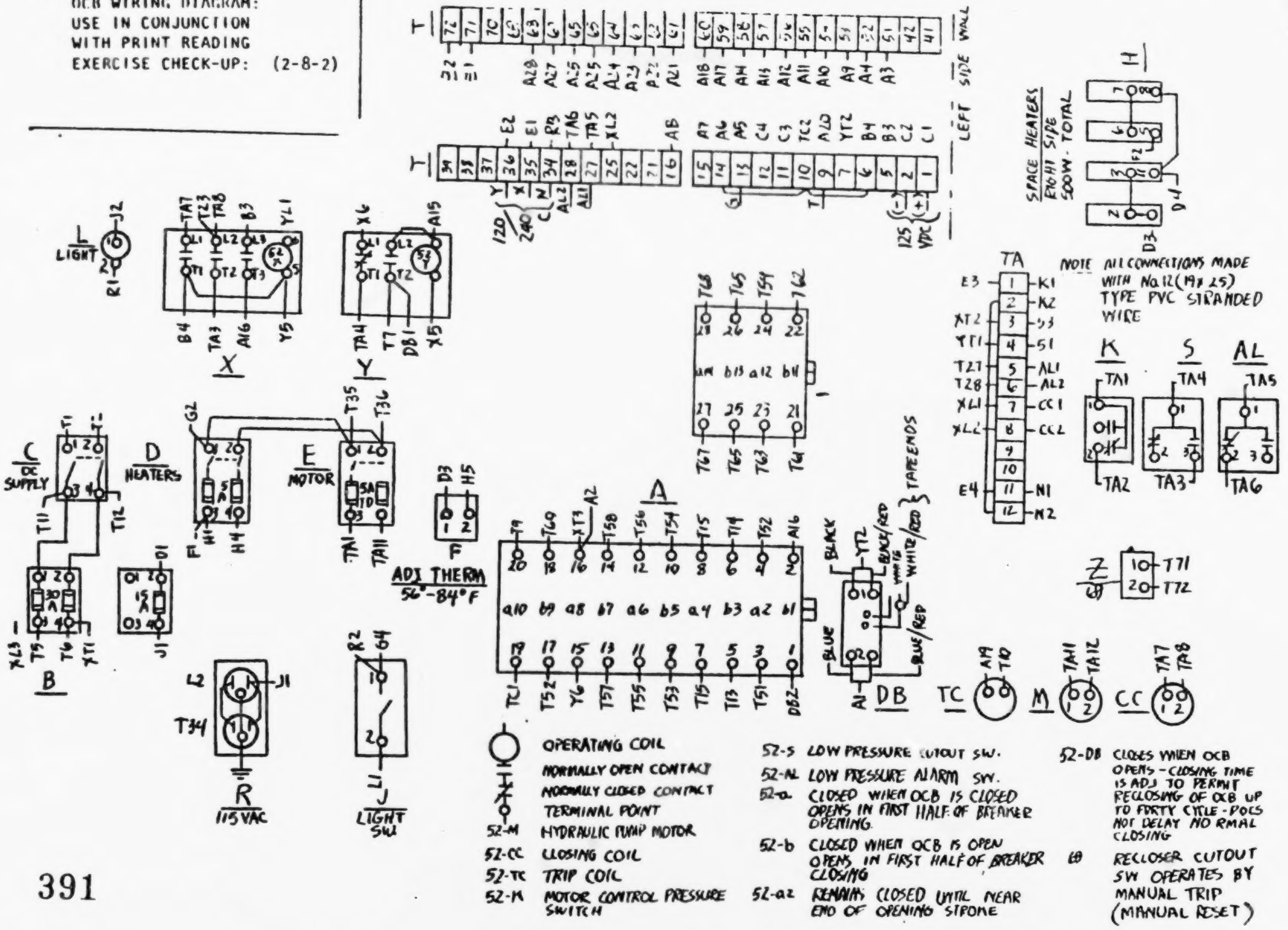
Each FT-1 test switch is identified with a letter ("A" through "J"). Place the correct letter in the $\underline{\overset{\text{T.S.}}{*}}$ brackets.

THREE LINE SCHEMATIC



C1
C2
C3
C0
T.S.
RD WH
R.D. W.H.
D.A.
50 51
50N 51N
21 22 23 24
25 26 27 28
29 30 31 32
13 14 15 16 17 18 19 20
E
F
BUS
LOAD
AØ
BØ
CØ
5 6
3 4
1 2
1 2 3 4 5 6
7 8 9 10 11 12
1200-5A MRBCT 600-5A
1200-5A MRBCT 600-5A

OCB WIRING DIAGRAM:
USE IN CONJUNCTION
WITH PRINT READING
EXERCISE CHECK-UP: (2-8-2)


T
LEFT SIDE WALL
L
LIGHT
X
Y
C
DC SUPPLY
D
HEATERS
E
MOTOR
F
ADJ THERM
56°-84°F
A
B
R
115 VAC
J
LIGHT SW
DB
TC
M
CC
TA
K
S
AL
Z
H
SPACE HEATERS
RIGHT SIDE
500W. TOTAL
TAPE ENDS
BLACK
BLUE
BLUE/RED
WHITE/RED
125 VDC
120
240

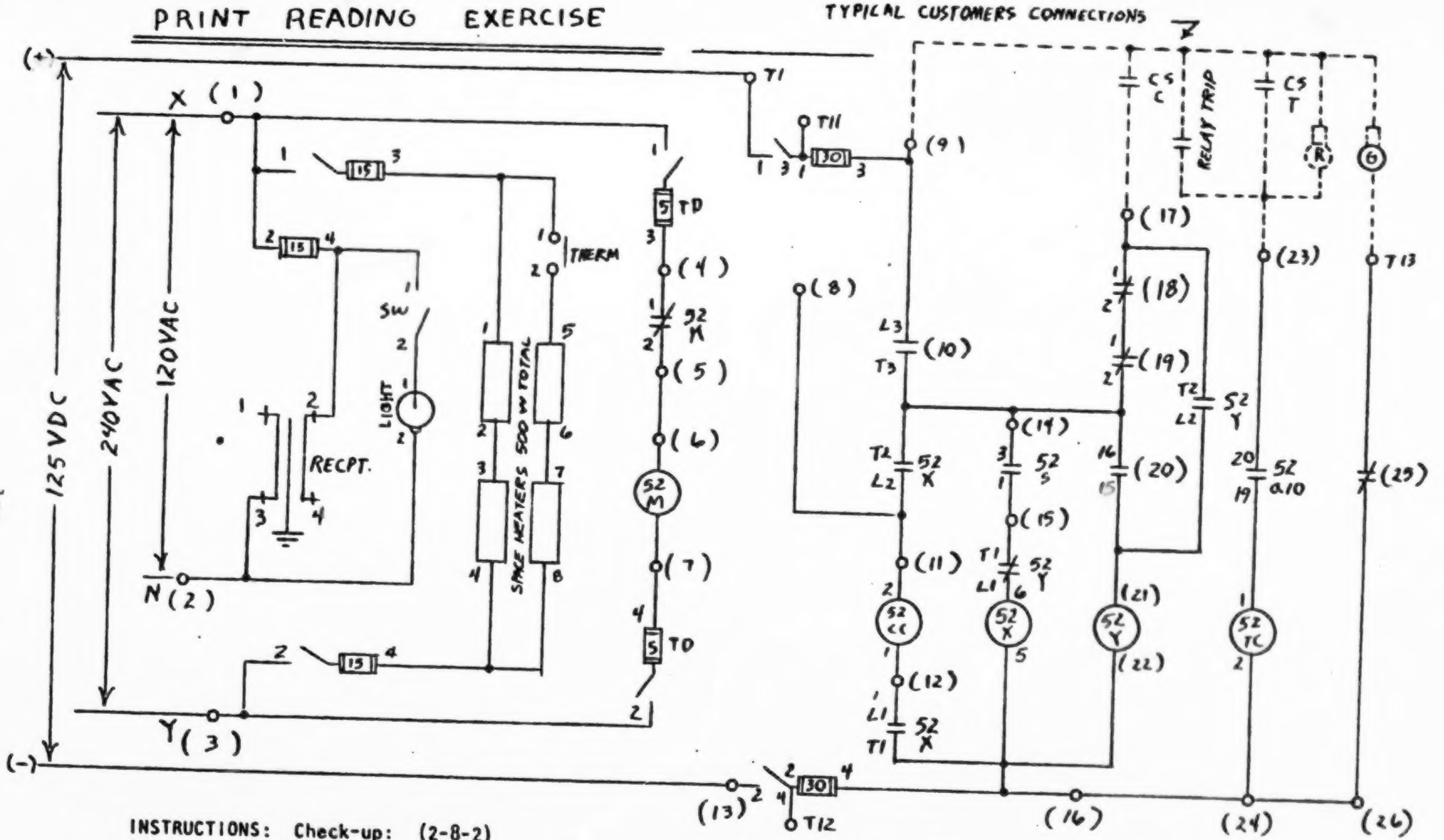
NOTE ALL CONNECTIONS MADE WITH No.12 (19x25) TYPE PVC STRANDED WIRE

OPERATING COIL
NORMALLY OPEN CONTACT
NORMALLY CLOSED CONTACT
TERMINAL POINT
52-M HYDRAULIC PUMP MOTOR
52-CC CLOSING COIL
52-TC TRIP COIL
52-K MOTOR CONTROL PRESSURE SWITCH

52-S LOW PRESSURE CUTOUT SW.
52-AL LOW PRESSURE ALARM SW.
52-a CLOSED WHEN OCB IS CLOSED OPENS IN FIRST HALF OF BREAKER OPENING.
52-b CLOSED WHEN OCB IS OPEN OPENS IN FIRST HALF OF BREAKER CLOSING
52-a2 REMAINS CLOSED UNTIL NEAR END OF OPENING STROKE

52-DB CLOSES WHEN OCB OPENS - CLOSING TIME IS ADJ TO PERMIT RECLOSING OF OCB UP TO FORTY CYCLE - DOES NOT DELAY NORMAL CLOSING
69 RECLOSER CUTOUT SW OPERATES BY MANUAL TRIP (MANUAL RESET)

PRINT READING EXERCISE


TYPICAL CUSTOMERS CONNECTIONS
(+)
(-)
125 VDC
240 VAC
120 VAC
X (1)
N (2)
Y (3)
15
LIGHT
SW
RECPT.
THERM
SPACE HEATERS 500 W TOTAL
5 TD
(4)
52 M
(5)
(6)
(7)
T1
T11
30
(8)
(9)
(10)
L3
T3
52 X
(11)
52 CC
(12)
(13)
T12
(14)
52 S
(15)
52 Y
(16)
(17)
(18)
(19)
(20)
(21)
(22)
(23)
(24)
(25)
(26)
52 a10
52 TC
CS C
CS T
RELAY TRIP
R
G
T13

INSTRUCTIONS: Check-up: (2-8-2)
Refer to the wiring diagram that accompanies this schematic and assign the correct terminal point or device number that will replace the number that appears enclosed within the parenthesis on this diagram - for example:

(1) = T35
(2) = ____
(3) = ____

(4) = ____
(5) = ____
(6) = ____
(7) = ____
(8) = ____
(9) = ____
(10) = ____

(11) = ____
(12) = ____
(13) = ____
(14) = ____
(15) = ____
(16) = ____
(17) = ____

(18) = ____
(19) = ____
(20) = ____
(21) = ____
(22) = ____
(23) = ____
(24) = ____

(25) = ____
(26) = ____

ANSWERS FOR CHECK-UP: (2-8-4)

CAPACITOR CONTROL WIRING DIAGRAM

Instructions: Select the answer you feel is the most accurate.

1. The "2-1" time delay relay when first energized
____(a) blocks opening of the vacuum switch.
__X_(b) blocks closing of the vacuum switch.
____(c) blocks both opening and closing of the vacuum switch.
____(d) turns on the green indicating lamp.

2. The "2-1" time delay relay will become energized
____(a) when the vacuum switch is first closed.
____(b) some adjustable time (3 to 5 minutes) after the vacuum switch is opened.
____(c) when the "43" switch is on automatic and the vacuum switch is opened.
__X_(d) any time the vacuum switch is opened.

3. The "2T-1" timing relay if energized will
____(a) remove the potential from the master control relay.
____(b) close the vacuum switch if the "43" switch is in the automatic mode.
__X_(c) trip the vacuum switch with no regard to the position of the "43" selector switch.
____(d) trip the vacuum switch only when the "43" switch is made automatic.

4. The 59X relay will be picked up (operated) whenever
____(a) there is a short circuit on the capacitor bank.
____(b) the 120/240 volt-ac gets above a preset value of volts.
__X_(c) the 120 volt-ac bus potential gets above a preset value of volts.
____(d) the 48 volt-dc gets above a preset value of volts.

5. The 59X relay will be reset or dropped out for
____(a) overvoltage on the 120/240 volt-ac circuit.
____(b) undervoltage on the 48 volt-dc.
____(c) any time the 43 switch is made manual.
__X_(d) low voltage on the 120 volt-ac bus potential.

6. The Kirk key interlock used on the ground switch for the capacitor bank has a set of contacts; number 2 and 7 that are
____(a) closed whenever the vacuum switch is open.
__X_(b) open whenever the ground switch is closed.
____(c) closed whenever the ground switch is closed.
____(d) closed whenever the 94 relay has operated.

7. The terminal block numbers on the vacuum switch to which the wires are connected that provide dc power to the vacuum switch are
__X_(a) 1 for positive, 2 for negative.
____(b) 3 for positive, 4 for negative.
____(c) 7 for positive, 9 for negative.
____(d) 1 for negative, 2 for positive.

8. The 59X relay when operated blocks closing of the vacuum switch
____(a) when in the automatic mode.
____(b) when in the manual mode.
__X_(c) when in either manual or automatic mode.
____(d) until the "2-1" time delay relay times out.

9. Contacts 2 and 3 of the 52X relay when closed
__X_(a) will energize the vacuum switch closing coil.
____(b) seal in the 52X coil.
____(c) de-energize the 52Y relay.
____(d) probably blow the 43 volt-dc control fuse.

10. The wires connecting to the 52Y relay coil are labeled
____(a) 3A and 3B.
____(b) 3 and 3A.
__X_(c) 3B and 7.
____(d) 1A and 2A.

11. The 59X relay operate coil cannot be picked up (energized) unless
__X_(a) the vacuum switch is closed.
____(b) the Kirk key interlock is adjusted correctly.
____(c) the "43" switch is made automatic.
____(d) the master controller is working properly.

12. When the 43 switch is in the automatic mode
____(a) the 52 control switch if operated will only open the breaker--not close it.
____(b) close the breaker but not open it.
____(c) allow the master controller to open the breaker when the frequency gets too high.
__X_(d) permit the master controller to control the breaker for preset load conditions.

13. Assume the breaker has tripped out and for some reason the breaker will not close again either on manual or automatic; which of the following is the most logical reason?
____(a) the master controller "1-1Y" contact is closed.
____(b) the 94 relay is sealed up.
____(c) the electric counter is not operating.
__X_(d) the 2-1 time delay relay has you blocked.

14. Assume the breaker is in the closed position and the red indicating lamp is not burning--it should be. The most logical reason is
____(a) the "43" switch is on manual mode.
____(b) one of the 120/240 volt-20 amp fuses located in the capacitor control cabinet has blown.
____(c) the 120 volt-ac bus potential has been interrupted.
__X_(d) the 30 amp, 48-volt-negative fuse is blown.

15. Term 6 on the "1-1" contact making wattmeter is "hot" to ground; i.e. it has a voltage of 120 volts to ground. This is an indication that
____(a) the potential coil of the controller could be open circuited.
____(b) the potential coil could be shorted out.
____(c) the FT-1 test switch "A" could be open.
__X_(d) the FT-1 test switch "B" could be open.

16. Referring to the master controller:
____(a) relay coil 1-1Y and relay coil 1-1X are operating from a half-wave rectifier circuit.
____(b) relay coil 1-1X and relay coil 1-1Y operate from a full-wave rectifier.
__X_(c) 1-1Y operates from ac and 1-1X operates from dc.
____(d) 1-1Y operates on dc, and 1-1X operates on ac.

17. The master controller device No. 1-1 is a contact making wattmeter. When the load through the main power transformer reaches a preset value of kilowatts, the contacts of the meter close and de-energize the 1-1X relay coil
____(a) which de-energizes the 1-1Y relay and thus trips the 94 relay.
__X_(b) and energizes the 1-1Y relay which seals in through its own contact.
____(c) by shorting out the 1-1X relay coil.
____(d) so as to reduce the load on the isolation transformer.

18. The ratio of the auxiliary current transformer is such that
____(a) when 1 amp flows in the primary circuit 2 amps flow to the current coil of the master controller.
__X_(b) 4 amps in the primary will produce only 2 amps in the secondary.
____(c) it will equal the ratio of the potential transformer.
____(d) the current vector will be more in phase with the potential transformer vector.

19. Assume the breaker is open and a voltmeter from terminal 27 to terminal 28 (capacitor control cabinet) shows a potential of approximately 48 volts dc. This would seem to indicate that the
____(a) green lamp is working and verifies the breaker is open.
__X_(b) auxiliary switch contacts 12 and 13 on the vacuum switch have an air gap; i.e. the wiring is incomplete.
____(c) the E.C. (operation counter) must have counted an operation.
____(d) the "2-1" agastat relay is energized.

20. In accordance with the National Electric Code, all high voltage capacitor cells must be equipped with internal resistors for the purpose of discharging the cells after line potential has been removed. One should keep in mind however, that the capacitor may retain a dangerous charge for several minutes. As a safety margin, it is best not to re-energize the capacitors for approximately 5 minutes. The relay in the control circuit that supervises this function is
____(a) the "2T-1" timing relay.
____(b) the 1-1 master controller.
____(c) the 59X/ER.
__X_(d) the "2-1" timing relay.

ANSWERS TO CHECK-UP: (2-8-5)

PRINT READING - TEST YOUR KNOWLEDGE

Refer to the accompanying elementary and wiring diagrams and answer the following twenty questions.

1. The wire No. for the wire that connects the 52Y relay coil to term block 10.
   7D

2. The wire No. for the wire that connects the 63MX relay coil to a 10 amp time lag fuse.
   36A

3. The wire No. for the wire that connects the thermostat to the 500 watt, 240 volt heater.
   35T

4. The wire No. for the wire that connects the 08 fuse to the 52Y relay coil.
   6

5. The wire No. for the jumper that connects term block 6 to term block 10A.
   6

6. The wire No. for the wire that connects the light to the duplex receptical.
   3

7. The wire No. of the wire that connects the 63MX relay coil to a contact of the 63M (pressure regulator).
   35B

8. The wire No. of the wire that connects the 63C contact (pressure switch--lockout--prevents operation at low pressure) and a 52b switch.
   7B

9. The wire No. of the wire that connects the breaker trip coil to negative.
   10A

10. The wire No.'s of the wires that provide the feed o fuse blocks H & M.
    35 & 36

11. What level of voltage is to be utilized to operate the motor?
    240 volts

12. With the circuit breaker open and the control power switches closed (energized) would a voltmeter connected to term block 13 indicate 125 volts negative or 125 volts positive?
    125V Negative

13. If in question 12, the circuit breaker were closed, would term block 13 be 125 volts negative, or 125 volts positive?
    125V positive

14. Should term block 3 be connected a hot wire or a neutral wire?
Neutral

15. A voltmeter connected from wire No. 4 to wire No. 4A and indicating 120 volts ac would indicate to you that 08 L 15 amp fuse was blown--true or false.
True

16. If a wire man removed and taped the wire connected to term block 36H, would this prevent the heater from operation?
No

For the following questions, select the most logical answer as to the cause of trouble.

17. The 1/3 H.P. motor fails to run and the pressure is below normal.
    (a) 10 amp fuse 08H is blown.
    (b) Someone has turned off the 120 volt ac circuit.
    (c) 63 MX relay coil is burned open.
    (c)

18. The operator after closing the OCB reports that the red indicating lamp does not light.
    (a) The red lamp is burned out.
    (b) The 52 Y2 contact is not functioning.
    (c) The 52T coil may have a short in it.
    (a)

19. The operator reports that he is unable to close the circuit breaker by means of the control switch.
    (a) The adjustable latch check switch is closed.
    (b) Wire No. 7C has a loose connection to the 52b switch.
    (c) The protective relays have burned open.
    (b)

20. The operator reports that the OCB attempts to close, but trips right back open when he attempts to close the OCB by means of the control switch.
    (a) The pressure is too low.
    (b) The 52Y1 contact is not closing.
    (c) Protective relay contacts have welded closed.
    (c)